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A TEXT-BOOK

OF

PHYSIOLOGY

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BY

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THIRD EDITION, REVISED AND ENLARGED

Illustrated with 419 Half-Tone and Other Engravings
Many in Colors

248143
27.10.30

PHILADELPHIA
F. A. DAVIS COMPANY, PUBLISHERS
1909

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Philadelphia, Pa., U. S. A.
Press of F. A. Davis Company,
1914-16 Cherry Street.

DEDICATED

TO THE MEMORY OF MY MOTHER

SARAH A. OTT

PREFACE TO THIRD EDITION.

THIS edition contains about seventy-six more pages than the second. Several old cuts have been removed. Twenty-five more cuts have also been inserted. The chapters upon Blood, Circulation, and Metabolism have been entirely rewritten. Respiration and Glands with an internal secretion have been revised to a considerable extent. Many facts in Applied Physiology and Therapeutics have been inserted for the benefit of the practitioner. The difficult things in Physiology have been made plain to the student. Discordant and hypothetical discussions have been avoided, which saves time for the reader. The theory usually accepted has been given. The greatest number of facts has been expressed with the smallest number of words, for Physiology is a positive science. I have not given any physiological technique, as it is in the laboratory and not in the text-book that the student should learn it. My thanks are due to Dr. John C. Scott, Demonstrator of Physiology, for the re-paging of the index.

ISAAC OTT.

PREFACE TO THE SECOND EDITION.

THE second edition of this book has been enlarged by the addition of two hundred and forty pages. Considerable new matter has been inserted, for Physiology is a science undergoing continuous development.

The subject of electro-physiology has been treated more comprehensively than in the first edition. The article upon the sympathetic system has been nearly entirely re-written. The latest acquisitions in this direction have been incorporated. The chapter on Vision has been entirely recast. In fact, nearly every page has been subjected to alterations and emendations. The work upon peristalsis of intestines in the Medico-Chirurgical laboratory has been incorporated. Over two hundred and fifty additional figures, many of them entirely original, have been included in this edition.

In the chapter on Reproduction, the first eleven pages and the part headed "Evolution" have been contributed by Dr. P. Fischelis, Demonstrator of Histology and Embryology, Medico-Chirurgical College.

My cordial thanks are due to Dr. E. T. Rehrig for the complete index.

ISAAC OTT.

CONTENTS.

CHAPTER I. PAGE
The Cell.. 1

CHAPTER II.
Chemical Constituents of the Body and Food................ 24

CHAPTER III.
Digestion.. 46

CHAPTER IV.
Absorption.. 135

CHAPTER V.
The Blood.. 166

CHAPTER VI.
The Circulation.. 219

CHAPTER VII.
Respiration.. 334

CHAPTER VIII.
Secretion.. 398

CHAPTER IX.
Metabolism.. 467

CHAPTER X.
Animal Heat.. 506

CHAPTER XI.
The Muscles.. 528

CHAPTER XII.
Voice and Speech.. 563

CHAPTER XIII.
Electro-physiology.. 575

CHAPTER XIV.
Nervous System.. 596

CHAPTER XV.

PAGE
Tactile Sense 722

CHAPTER XVI.

Taste 737

CHAPTER XVII.

Smell 742

CHAPTER XVIII.

Hearing 749

CHAPTER XIX.

Vision 771

CHAPTER XX.

Cranial Nerves 820

CHAPTER XXI.

Reproduction 841

Index 873

LIST OF ILLUSTRATIONS.

FIG. PAGE

1. Vegetable Cell. (DUVAL) 6
2 Cell with Reticulum of Protoplasm Radially Disposed. From Intestinal Epithelium of a Worm. (CARNOY) 8
3. Amœba proteus. (LEIDY) 9
4. To Show the Changes in the Nerve-cell Due to Age. (From HOWELL) 23
5. Yeast Fungus. (After HARLEY) 28
6. Specimens of Milk Viewed through the Microscope. (LANDOIS) 41
7. Longitudinal Section of a Molar Tooth of Man. × 8. (SOBOTTA) 52
8. Portion of the Crown of a Longitudinal Section of a Human Premolar. × 200. (SOBOTTA) 53
9. Portion of a Longitudinal Section of the Root of a Human Molar Tooth. × 200. (SOBOTTA) 54
10. Histology of the Salivary Glands. (LANDOIS) 55
11. Parotid of Cat. (L. MÜLLER) 64
12. Parotid of a Rabbit in Fresh State. (LANGLEY) 65
12a. Schema of Nerves of Parotid Gland 66
12b. Schema of Nerves of Submaxillary Gland 67
13. Human Stomach. (After SAPPEY) 70
14. Vertical Section through the Gastric Mucous Membrane. (LANDOIS) 71
15. Gastric Contents. Collective Microscopic Picture. × 350. (LENHARTZ) 72
15a. Functional Division of Stomach. (HUTCHISON) 73
16. Hourly Variations of the Secretion of Gastric Juice in the Dog after a Meal of Meat, Bread, and Milk. (PAWLOW) 78
17. Hourly Variations of the Digestive Power of the Gastric Juice in the Dog after a Meal of Meat, Bread, and Milk. (PAWLOW, GLEY) 79
18. Dog's Stomach. (PAWLOW) 81
19. Dogs to whom a Fictitious Meal is Given. They have a fistula in the œsophagus and a fistula in the stomach. After a photograph taken in the laboratory of Pawlow. (GLEY) 83
20. Portion of the Wall of the Small Intestine Laid Open to Show the Valvulæ Conniventes. (BRINTON, RAYMOND) 90
21 Blood-vessels of an Intestinal Villus. (LANDOIS) 91
22. Mucous Membrane of the Jejunum, Highly Magnified. (Schematic.) (TESTUT, RAYMOND) 92
23. Effect of Albumose, increasing Peristalsis 96
24. The Pancreas. (Posterior View.) (BOURGERY) 97
25. Schematic Section of Pancreas. (VIALLETON) 98
26. Pancreas of Rabbit Observed During Life. (KÜHNE and LEA) 99
27. Hourly Variations of the Pancreatic Secretion after a Meal of Meat, Bread, and Milk. (After a curve obtained in the laboratory of Pawlow by one of his pupils, A. WALTHER) 100
28. Liver of Man. (DUVAL) 109
29. Diagrammatic Representation of an Hepatic Lobule. (LANDOIS) 111
30. Glycocholic Acid. (DUVAL) 114
31. Taurin. (DUVAL) 115
32. Crystals of Cholesterin. (DUVAL) 117
33. Curves Showing the Velocity of Secretion of Bile into the Duodenum on (1) a diet of milk, uppermost curve; (2) a diet of meat, middle curve; (3) a diet of bread, lowest curve. The divisions on the abscissa represent intervals of thirty minutes; the figures on the ordinates represent the volume of secretion in cubic centimeters. (HOWELL, after BRUNS) 118
34. *A*, Liver-cells during fasting. *B*, Cells filled with Glycogen. (HEIDENHAIN) .. 121
35. Aspect of an Intestinal Loop before and after Section of its Nerves. (ARMAND MOREAU, after GLEY) 127
36. Stool. Collective Microscopic Picture. × 350. (Partly after NOTHNAGEL) (LENHARTZ) 129
37. Inhibitory apparatus of Ano-spinal Center 131
37a. Rhythmic Systolic Movements of Anal Sphincter of cat after Transverse Section of Lumbar Part of Spinal Cord. (OTT, from LUCIANI) 132
38. Osmometer. (COHEN) 138
38a. Schema Showing Routes by which the Digested Foods Reach the Blood. (MORAT) 143
39. *A*, Section of Villus of Rat killed during Fat Absorption. (SCHÄFER.) *B*, Mucous Membrane of Frog's Intestine during Fat Absorption. (SCHÄFER). 147
40. Lacteals of a dog during Digestion. (COLIN) 149
41. The Superficial Lymphatics of the Internal Surface of the Lower Limb. (SAPPEY) 150

FIG. PAGE
42. Topography of the Thoracic Duct (Zuckerhandl.) (Raymond) 151
43. Section of Dog's Intestine, showing Villi. (Cadiat) 155
44. Diagram to Show Relation of the Secreting Cell of a Gland to the Blood and Lymph-supply. (Starling) 158
45. Diminution of the Flow of Lymph under the Influence of the Slowing of the Heart. Dog narcotized with morphia and chloroform. (L. Camus) 160
46. Dog with Medulla Divided. (L. Camus and E. Gley) 161
46a. Viscosimeter of Ostwald. (Asher) 169
47. Blood-corpuscles of Different Animals. (Thanhoffer) 172
48. *A*, Progressive Pernicious Anæmia. *B*, Lienal (Splenic) Leukæmia. *C*, Lienal (Splenic) Leukæmia. *D*, Acute Leukæmia .... Facing 172
49. Human and Amphibian Blood-corpuscles. (Landois) 173
50. Hæmacytometer of Thoma-Zeiss. (Lahousse) 175
51. Daland's Hæmatocrit 176
52. Red Blood-corpuscles. (Landois) 176
53. Leucocytes of Man, showing Amœboid Movement. (Landois) 181
54. Blood-plates and their Derivatives. (Landois) 184
55. Blood-crystals of Man and Different Animals. (Thanhoffer and Frey) 187
56. Teichmann's Hæmin-crystals. (Lahousse) 190
57. Sorby-Browning Microspectroscope 193
58. Von Fleischl Hæmometer. (Lahousse) 195
59. Dare's Hæmoglobinometer. (Lenhartz) 196
60. Relative Proportion of Corpuscles and of Plasma. (Human Blood.) (Langlois) 198
61. Delicate Fibrin Coagulum (from Croupous Pneumonia.) × 350. (Lenhartz) 199
61a. Stages in Widal Reaction. (After Robin) 215
62. Anterior Surface of the Heart. (Bourgery) 222
63. Heart of the Cow, with Left Auricle and Ventricle Laid Open. (Müller) 223
64. Diagram of Mammalian Heart. (Beclard) 224
65. Valves of Heart 225
66. Course of Muscular Fibers of Heart. (Landois) 227
67. Course of the Ventricular Muscular Fibers. (Landois) 228
68. Diagram of the Circulation. (Duval) 230
69. A Cardiac Cycle. (Starling) 234
70. Sanderson Cardiograph 236
71. Cardiogram (*B*) with Simultaneous Record of Heart-sounds (*A*). (Hürthle, Starling) 237
71a. Diagram showing Relations of Cardiogram of Pulse in Carotid, Jugular, and Radial to each other. (Hay) 238
72. Magnified Curve of the course of pressure within the left ventricle and the aorta of the dog, the chest being open; to be read from left to right. Recorded simultaneously by two elastic manometers with transmission by liquid. (Porter) 240
73. The Action of the Semilunar Valves. (Chauveau) 243
74. The Action of the Tricuspid Valve. (Chauveau) 244
75. Heart of the Frog. (Livon) 251
76. Schema of Ligatures of Stannius. (Hedon) 253
76a. Right Auricle and Ventricle of the Calf. (Keith) 257
77. A Case of Heart Block. (Hewlett) 258
78. Course of Vagus Nerve in Frog. (Stirling) 260
79. Tracing by Lever Attached to Frog's Heart on Stimulation of the Pneumogastric nerve. (Foster) 262
80. Arrest of the Heart of a Rabbit by Irritation of the Peripheral End of the Pneumogastric in the Neck. (Gley) 263
81. Irritation of Nervous Depressor in a Rabbit, Causing a Fall of Arterial Tension. (Gley) 264
82. Innervation of Heart. (Powell) 265
83. Diagram of the connections of the Depressor Nerve in the Rabbit and Dog, according to Cyon. It will be noticed that in the latter animal the depressor nerve runs in the vagus trunk for the greater part of the course. (Starling) 266
84. Schema of Innervation of the Heart of a Dog. (Morat) 267
85. Acceleration of Heart following an Irritation of an Efferent Branch of the First Thoracic Ganglion in a Curarized Dog. Action of Accelerator Nerve. (Gley) 269
86. "Staircase" of Beats of a Stanniused Frog's Heart Excited by Maximal Induction Shocks at Intervals of three Seconds. (Waller) 273
87. Refractory Period of Heart-muscle of Frog, with Compensatory Pause 274
88. To Illustrate the Varying Excitability of the Frog's Heart at Different Periods of Systole and Diastole. (Waller) 275
89. Variations in Tonus of Auricle of Terrapin's Heart. (Fano) 277
90. Weber's Schema 283
91. Marey's Intermittent Afflux Apparatus. (Lahousse) 286
92. Marey's Sphygmograph. (Yeo) 289
93. Dudgeon's Sphygmograph. (Lahousse) 290
94. Sphygmogram Magnified. (Lahousse) 291
95. Frog's Web, Highly Magnified. (Yeo, after Huxley 293
96. Showing the Relative Heights of Blood-pressure in Different Blood-vessels. (Yeo) 296

FIG. PAGE
97. Variations in Pressure. (LANDOIS) 297
98. Manometer of Mercury for Measuring and Registering Blood-pressure. (YEO). 299
99. Ludwig's Kymograph. (YEO) 300
100. Blood-pressure Curve Recorded by the Mercurial Manometer. (YEO) 301
101. Cardiac Manometer. (LAHOUSSE) 302
102. Riva-Rocci Sphygmomanometer 304
102a. Erlanger's Apparatus for Determination of the Blood-pressure in man. (TIGERSTEDT) 305
103. Traube-Hering Curves. (FREDERICQUE) 308
103a. Schema of the Normal Jugular Pulse. (FRANCOIS FRANK) 311
104. Ludwig's Stromuhr. (LANDOIS) 313
105. Tachogram. (LORETT) 315
106. Curves Obtained by Enclosing the Hind Limb of a Cat in the Plethysmograph and Stimulating the Peripheral End of the Cut Sciatic Nerve (Bowditch and Warren, 1886). (HOWELL) 322
107. Effect of Irritation of the Splanchnic Nerve on the Aortic Pressure. (GLEY).. 323
108. Carotid Pressure in Curarized Dog after Section of Medulla *A*, and after Destruction of the Cord *B*. (GLEY) 328
109 Elevation of Arterial Pressure by Vasoconstriction. A result of irritation of the central end of sciatic in curarized dog. (HEDON) 330
110. Fick's Plethysmograph 331
111. Human Respiratory Apparatus. (DUVAL) 338
112. Bronchia and Lungs. Posterior View. (SAPPEY) 339
113. Mold of a Terminal Bronchus and a Group of Air-cells Moderately Distended by Injection, from the Human Subject. (ROBIN) 341
114. Termination of a Bronchus in an Alveolus 342
115. Section of the Parenchyma of the Human Lung, Injected Through the Pulmonary Artery. (SCHULZE) 343
116. Diagrammatic Representation of the Action of the Diaphragm. (BECLARD).. 345
117. The Action of the Ribs in Man in Inspiration. (BECLARD) 346
118. Schema of Respiratory Mechanism in Inspiration. (LAULANIE) 347
119. Schema of Respiratory Mechanism in Expiration. (LAULANIE) 348
120. Schema of Action of Intercostal Muscles. (LANDOIS) 349
121. Tracing of a Respiratory Movement. (FOSTER) 351
122. Marey's Tympanum and Lever. (SANDERSON) 352
123. Spirometer. (FREDERICQUE) 353
124. Gad's Aeroplethysmograph. (KRUSICH) 356
125. Number of Respirations by Man at Different Ages. (QUETELET) 357
126. Carotid Pressure in Dog. Acceleration of Heart at the Moment of Inspiration is Well Marked. (LANGLOIS) 358
127. Apparatus to Illustrate Relations of Intra-thoracic and External Pressures. (After BEAUNIS) 359
128. Illustrating Atmospheric Pressure During Respiration 360
129. Comparison of Blood-pressure Curve with Curve of Intra-thoracic Pressure. (M. FOSTER) 360
130. Illustrating Arterial Blood-pressure During Respiration 361
131. Illustrating Venous Blood-pressure During Respiration 362
131a. The Respiratory Center and Its Connections. (HUTCHISON) 365
132. Rabbit (morphine gr. $^{1}/_{3}$ injected hypo.). (DR. W. H. GOOD) 367
133. Arrest of Respiration in State of Expiration. (HEDON) 369
134. Strong Irritation of Divided Right Vagus. (GLEY) 370
135. Apparatus for Taking Tracings of the Movements of the Column of Air in Respiration. (FOSTER) 372
136. Shows the Position to be Adopted for Effecting Artificial Respiration in Cases of Drowning. (SCHAEFER, HOWELL) 376
137. Cheyne-Stokes Respiration. (WALLER) 379
138. Ludwig's Mercurial Air Pump to Extract Blood Cases. (LAHOUSSE) 380
139. Schema of the Large Respiration Apparatus of Pettenkofer. (FREDERICQUE). 381
140. Showing Constituents of Air Inspired and Expired. (LANGLOIS) 382
141. Variations of Respiratory Quotient According to Food Taken. (LANGLOIS).. 383
142. Variations of Respiratory Quotient According to the Food Taken. (LANGLOIS). 384
143. Relative Proportion of Gases of Blood. (LANGLOIS) 386
144. Structure of the Thyroid (Morat and Doyon). Lobule of the Thyroid after an Injection of the Lymphatic Vessels with Nitrate of Silver. Semi-schematic. (VIALLETON) 401
145. Parathyroid of Dog (Morat and Doyon). (VIALLETON) 402
146. Illustrating Nicholson's Article on Thyroid Treatment in a Cretin (Arch. of Ped., June, 1900). (RAYMOND) 403
146a. Arrest of Development in a Sheep After Thyroidectomy. (VON EISELSBERG). 404
146b. A Case of Myxœdema. (JEANDELIZE) 405
147. Effect of Iodothyrin on Intestinal Peristalsis 406
147a. Convulsive Movements after Thyro-parathyroidectomy in Dog. (GLEY) 407
147b. The Four Parathyroids in Man. (ZUKERKANDL) 408
148. Effect of Extract of Spleen on Intestinal Peristalsis 411
149. Adrenal Capsules of a Rabbit. (MORAT and DOYON) 411
150. Section of Adrenal. (VIALLETON) 412
151. Effect of Adrenalin on the Volume of Inspired and Expired Air. Tracing with Gad's Aeroplethysmograph 413
152. Effect of Adrenalin on Intestinal Peristalsis 414

FIG. PAGE
153. Cat. One drop of adrenalin solution and ten drops of 1-per-cent. solution of nitroglycerin, mixed and then injected per jugular........................ 414
154. Turtle Heart, Suspended by Lever.. 415
155. Effect of Suprarenal Extract upon Muscle-contraction in the Frog. (Schäfer). 416
155a. A Case of Acromegaly. (Caselli).. 419
156. Mammary Gland of Human Female. (After Liegeois)........................ 421
157. Dog's Mammary Gland in First Stage of Secretion. (Heidenhain).......... 423
158. Mammary Gland of the Dog, Second Stage of Secretion. (Heidenhain)...... 424
159. Sweat Gland. (Hedon).. 425
160. Section of Sweat-glands of Cat.. 427
161. Relations of the Kidney. (After Sappey)................................. 432
162. Secretion of Kidney. (Landois).. 434
163. Diagram of the Course of Two Uriniferous Tubules. (Landois)............. 435
164. Structures of Kidney. (Landois)... 436
165. Longitudinal Section of a Malpighian Pyramid. (Landois)................. 437
166. Blood-vessels and Uriniferous Tubules of the Kidneys. (Semidiagrammatic.) (Landois) 438
167. Urea from Human Urine. (Funke)... 443
168. Micrococcus Ureæ. × 500. (After von Jaksch)............................. 444
169. Uric-acid Crystals with Amorphous Urates. (Purdy, after Peyer).......... 446
170. Uric Acid, Effect of on Intestinal Peristalsis.......................... 447
171. Urate of Soda and Crystals of Uric Acid (*h*), Oxalate of Lime (*o*), and Cystin (*c*). × 350. (Lenhartz).. 448
172. Effect of Xanthin on Muscle Curve, Causing an Extra Contraction during the Relaxation. (J. F. Ulman).. 450
173. Leucin in Balls; Tyrosin in Sheaves. (Peyer)............................ 451
174. Crystals of Ammonio-magnesium Phosphate. (After Ultzmann).............. 456
175. Feathery Crystals of Triple Phosphate. × 350. (After Tyson)............. 457
176. Crystals of Phenylglucosazone. (Purdy, after v. Jaksch)................. 460
177. Blood-pressure and Volume of Kidney. (Stirling, after Roy).............. 462
178. Diagram of Nerve-supply to Bladder. (Nawrocki, Skabitchewsky, and Starling) 465
178a. Schematic Outline of Ventilation System. (Benedict).................... 469
178b. Horizontal Section of Respiration Calorimeter. (Benedict)............... 470
178c. Catabolism, Heat Production, and Pulse Rate. (Benedict)................ 496
178d. Catabolism During a Seven Day Fast. (Benedict)......................... 497
179. Variations in the Bodily Temperature during Health within Twenty-four Hours. (Landois).. 510
180. Human Calorimeter 514
181. Bilateral Puncture of the Tuber Cinereum of Rabbit Through Roof of Mouth.. 517
182. Puncture of Tuber Cinereum in Rabbit, Showing Effect on Respiration, Arterial Tension, Pulse, and Temperature..................................... 518
183. Cortex of Cat's Brain 520
184. Lesions of Cortex in Man, Causing Elevations of Temperature............. 521
185. Curves of Temperature and Respiration when Cortex is Removed and the Animal is Artificially Heated 522
186. Curve of Temperature and Respiration when the Tuber Cinereum is Destroyed and the Animal is Artificially Heated..................................... 523
187. Heat Production and Heat Dissipation in Man during a Paroxysm of Malarial Fever—a Great Increase of Heat Production................................ 525
188. Histology of Muscular Tissue. (Ellenberger)............................. 531
189. Unstriped Muscular Tissue. (Ellenberger)................................ 537
190. The Pendulum Myograph. (Foster)... 545
191. A Muscle-curve Obtained by Means of the Pendulum Myograph. (Foster).. 547
192. Arrangement of Apparatus in Conducting Experiments on Nerve and Muscle. (Stirling) 548
193. Fatigue-curves of Frog's Muscle. (Waller)............................... 549
194. Influence of Increasing the Strength of the Stimulus upon the Contraction of Skeletal Muscle 549
195. An Experiment to Show that a Contracting Muscle does not Change its Volume 550
196. Apparatus for Measuring the Velocity of the Wave of Muscular Contractions. (Marey) 551
197. Rate of Conduction of the Contraction Process along a Muscle as shown by the Difference in the time of Thickening of the two Extremities. (Marey, Howell) 552
198. Tracing of a Double Muscle-curve. (Foster).............................. 552
199. Progress in Fusion of Contraction. (Laulanié)........................... 553
200. 1. Imperfect Tetanus, 15 Contractions per second. 2. Perfect Tetanus. (Laulanié) 554
201. Extensibility of Elastic Band and Muscle. (Waller)...................... 556
202. Extensibility of Muscle in Various States. (Waller)..................... 557
203. Mosso's Ergograph 559
204. Ergographic Curves. (After Mosso)....................................... 560
205. Ergographic Curve of a Case of Addison's Disease, Showing Rapid Exhaustion of Muscle. (Langlois)... 561
206. Fick's Work Adder. (Laulanié)... 561
207. Curve of Contraction of the Unstriped Muscle of Müller in Dog. (Laulanié). 562
208. The Larynx as Seen with the Laryngoscope. (Landois)...................... 564

FIG. PAGE
209. Action of the Muscles of the Larynx. (BEAUNIS) 565
210. Schematic Horizontal Section of Larynx. (LANDOIS) 566
211. Schematic Closure of the Glottis by the Thyro-arytenoid Muscles. (LANDOIS). 567
212. The Posterior Rhinoscopic Image. (BOSWORTH) 569
213. Position of Vocal Cords on Uttering a High Note. (LANDOIS) 570
214. Daniell Cell 576
215. DuBois Nonpolarizable Electrodes. (LAHOUSSE) 579
216. Tetanizing Key of DuBois-Reymond. (After ROSENTHAL) 580
217. Pohl's Commutator. (LAHOUSSE) 581
218. DuBois-Reymond's Induction Apparatus. (WALLER) 583
219. Principle of Simple Rheocord 584
220. Schema of Apparatus to Study nIfluence of Rapid Variations of the Constant Current by the Rheonome of von Fleischl. (LAHOUSSE) 585
221. Schema of Experiment to Measure the Rapidity of the Muscle Current by the Aid of the Differential Rheotome of Bernstein. (LAHOUSSE) 586
222. The Nerve-muscle Preparation. (STIRLING) 587
223. Thompson Galvanometer 588
224. Diagram of Capillary Electrometer. (STARLING) 589
225. Direction of Current of Daniell Cell 590
226. Direction of Current of Injured Muscle. (WALLER) 590
227. Schema Representing the Inequalities of Electric Tensions upon the Natural Longitudinal Surface and upon the Artificial Transverse Surface of a Muscle-cylinder. Also the direction of the electric currents from the exterior to the interior of the muscle. (LAHOUSSE) 591
228. The Negative Variation (Frog's Gastrocnemius). (WALLER) 592
229. Arrangement of Parts to Show Secondary Contraction in Muscle. (After ROSENTHAL) 593
230. Effect of Chloroform upon the Electrical Responses of Isolated Nerve. (WALLER) 594
231. The Structure of Nervous Tissue. (LANDOIS) 597
232. Cells from Anterior Horn of Human Spinal Cord. Ganglion Cells. (RAMON Y CAJAL.) Neuroglia. (WEIGERT) 598
233. Ganglion Cell from Sympathetic Ganglion of Frog; Greatly Magnified, and Showing Both Straight and Coiled Fibers. (After QUAIN) 599
234. A Piece of Medullated Nerve-fibril of Man, Nucleus and Axis Cylinder Stained by Carmine. (SOBOTTA) 601
235. A Piece of Medullated Nerve of Man. It shows Ranvier's Constrictions and Lantermann's Incisures. (SOBOTTA) 601
236. Two Nerve-pairs at Their Origin in the Spinal Cord—Anterior and Posterior Roots. (MORAT) 612
237. Transverse Section of the Spinal Cord 618
238. Section of Spinal Cord, Showing the Less Well-known Tracts 621
239. Medulla Oblongata, Pons, Cerebellum, and Pes Pedunculi. Anterior View, to Demonstrate Exits of Cranial Nerves. (EDINGER) 623
240. The Three Pairs of Cerebellar Peduncles. (After HIRSCHFELD and LEVEILLÉ). 624
241. Metencephalon, Mesencephalon, and Thalamencephalon, from the Dorsal Surface. (GORDINIER, after OBERSTEINER) 626
242. Diagrammatic Transverse Section of the Spinal Bulb × 3, at about the middle of the olivary body, to illustrate the principal nuclei and tracts at that level. (WALLER, after SCHWALBE) 627
243. Cross-section of the Oblongata through the Decussation of the Pyramids. (After HENLE) 628
244. Section of Medulla Oblongata at the Level of the Decussation of the Pyramids —Motor Decussation. (M. DUVAL.) Section of Medulla Oblongata at the Upper Part—Sensory or Fillet Decussation. (M. DUVAL) 630
245. The Base of the Brain. The Left Lobus Temporalis is in Part Represented as Transparent in Order that the Entire Course of the Optic Tract Might be Seen. (EDINGER) 633
246. Diagram to Illustrate Some of the Connections of the Nuclei of the Nerves to the Ocular Muscles. (STARLING, after HELD) 635
247. Diagrammatic Transverse Section Through the Crus Cerebri and Anterior Corpora Quadrigemina. (WALLER, after OBERSTEINER) 636
248. Section of the Crus Cerebri. (MORAT) 637
249. The Mesial Fillet, Ending Chiefly in the Ventral Nucleus of the Optic Thalamus and then United by New Neuraxons (Upper Fillet) to Parietal Cortex. 640
250. View from the Side and Slightly from Above and Behind of the Right Hemisphere of a Simply Convoluted European Brain. (QUAIN) 641
251. Lateral Aspect of Brain. (EDINGER) 643
252. Mesial Aspect of Left Hemisphere of a European Brain. (QUAIN) 644
253. Longitudinal Section Through the Middle of an Adult Brain. The Posterior portion of the thalamus, the crura cerebri, etc., have been removed, in order to expose the inner surface of the temporal lobe. (EDINGER) 645
254. Section Through the Cerebral Cortex of a Mammal. (EDINGER and CAJAL) .. 646
255. The Brain-structures from the Thalamus to the Spinal Cord (the "Brain-stem"). (EDINGER) 647
256. Thalamus and Corpora Quadrigemina Seen from the Side. (EDINGER) 648
257. Median Sagittal Section Through the Interbrain and the Structures Posterior to it. (EDINGER) 649
258. Median Section of the Brain. (QUAIN) 651

FIG. PAGE
259. So-called Ganglionic Gray Matter of the Cerebral Trunk. (After Charpy.) Gray Masses Superadded to the Sensori-motor Nuclei. (Morat) 652
260. Ideal Horizontal Section Through the Right Hemisphere and Basal Ganglia. (Waller, after Charcot) 653
261. Internal Capsule. (Sherrington) 654
262. Motor Tract. (Morat) 655
263. Sensory Tract. (Morat) 657
264. *D*, Dubois-Reymond's Spring Myograph to Measure the Rapidity of the Nerve Current in Motor Nerves. (Lahousse) 661
265. Curves Illustrating the Measurement of the Velocity of a Nervous Impulse (Diagrammatic). (Foster) 662
266. Method of Studying Physiological Electrotonus. (Lahousse) 664
267. Schema of Apparatus for the Study of the Law of Contractions in the Frog. (Lahousse) 665
268. Scheme of Electrotonic Excitability 666
269. Pflüger's Law of Contraction of Nerve-muscle Preparation 667
270. Anelectrotonic Current. Polarizing Current. Katelectrotonic Current. (Waller) 670
271. Elementary Reflex Arc. Course of Sensory Impressions and a Motor Impulse, Passing Through the same Level of the Spinal Cord. (Morat) 671
272. Diagram of the Roots of a Spinal Nerve, Showing Effect of Section. (Landois). 676
273. Floor of Fourth Ventricle of Rabbit. (Hedon) 683
274. Horizontal Section Through the Cerebellum. (After B. Stilling) 685
275. Section of Cerebellum of Man Treated by Golgi Method. (Sobotta) 687
276. Schema Showing the Origin and Course of the Fibers of the Peduncles of the Cerebellum. (Edinger) 688
277. Connections of the Cerebellum with Cerebrum, Pons, and Spinal Cord. (Schema Charpy.) (Morat) 690
278. Effects of Removal of Cerebellum. (Dalton) 691
279. The Motor Area and its Subdivisions on the Lateral Aspect of the Hemicerebrum of the Chimpanzee. (Grünbaum and Sherrington) 696
280. The Motor Areas and Centers on the Mesial Aspect of the Hemicerebrum of the Chimpanzee. (Grünbaum and Sherrington) 697
281. Areas and Centers of the Lateral Aspect of the Human Hemicerebrum. (Mills) 698
282. Areas and Centers of the Mesial Aspect of the Human Hemicerebrum. (Mills) 699
283. Lateral View of a Human Hemisphere, Showing the Bundles of Association Fibers. (Starr) 702
284. Effects of Ablation of Cerebrum. (Dalton) 705
285. Curve of the Depth of Sleep. (Piesbergen) 707
286. Pyramid Cells of the Marmot in Two Different Conditions. (After Querton). 708
287. Diagram of the Origin, in Man, of the Efferent Autonomic Fibers from the Central Nervous System. (Langley) 712
288. Ganglia and Fibers. (Langley) 713
289. Diagram of the Main Distribution of the Bulbar and Sacral Autonomic Fibers. (Langley) 714
290. Diagram of the Great Sympathetic, Representing its Visceral Distribution. (Morat) 715
291. Diagram of the Great Sympathetic, Representing its Cutaneous Distribution and its Two Orders of Fibers of Projection 716
292. An Afferent Sympathetic Fiber 717
293. Efferent Sympathetic Fiber 718
294. Cross-section of Neurotendinous Nerve End-organ of Rabbit from Tissue stained in Methylene Blue. (Huber and Dewitt) 724
295. Histology of the Skin and the Epidermoidal Structures. (Landois) 726
296. Cutaneous Papillæ Deprived of Their Epidermis and the Vessels Injected. (Landois) 728
297. Vater-Pacinian Corpuscle from the Mesentery of the Cat, Fixed in a Platinum Chlorid-osmic Acid Solution. × 45. (Sobotta) 729
298. Krause's Corpuscle. (Hedon) 730
299. Transverse Section of Two Grandry's Corpuscles from the Tongue of a Duck. × 450. (Sobotta) 731
300. Topography of Sensibility to Cold and Heat in the Same Region of the Anterior Surface of the Thigh. (Goldscheider, Hedon) 733
301. Structure of the Taste-organs. (Landois) 739
302. Sternberg's Gustometer 740
303. Innervation of the External Wall of the Nasal Fossa. (Testut) 742
304. Internal Structure of Nose. (Bishop) 743
305. Diagram of the Connections of Cells and Fibers in the Olfactory Bulb. (Schäfer, in Quain's Anatomy) 744
306. Zwaardemaker's Olfactometer 747
307. Diagram of the External Surface of the Left Tympanic Membrane. (Hensen). 750
308. Tympanic Membrane and Auditory Ossicles, seen from the Tympanic Cavity. (Landois) 751
309. Left Tympanum and Auditory Ossicles. (Landois) 752
310. Scheme of the Organ of Hearing. (Landois) 753
311. Scheme of the Labyrinth and Terminations of the Auditory Nerve. (Landois). 755

FIG. PAGE
312. Section through the Uncoiled Cochlea (I) and through the Terminal Nerve Apparatus of the Cochlea (II). Munk, after Hensen) 756
313. Section of the Ductus Cochlearis and the Organ of Corti. (After Landois) 757
314. Connections of Cochlea with Central Nervous System. (Paton) 758
315. Connections of Semi-circular Canals with Central Nervous System. (Paton). 759
316. I. The Mechanics of the Auditory Ossicles. (After Helmholtz.) II. Section of the Middle Ear. (Munk, after Hensen) 763
317. Schema of the Semi-circular Canals, the Posterior Part of the Skull Removed. (Hedon, after Ewald) 767
318. Semi-circular Canals on Right Side Destroyed. Commencing rotation of head of pigeon about five days after operation. (After Ewald) 768
319. Twisting of the Head of a Pigeon twenty days after removal of all the semi-circular canals on the right side. (Ewald, J. R.) 769
320. Position of Pigeon's Head after removal of all the semi-circular canals on both sides. (Ewald, J. R.) 770
321. Diagram of Horizontal Section through the Human Eye. (Yeo) 772
322. Anterior-posterior Section of the Eyeball. (Leveillé) 773
323. Section through the Human Cornea. (Böhm and Davidoff) 774
324. Corneal Corpuscles of Dog. (Böhm and Davidoff) 774
325. Corneal Nerves of the Pig. (Rollet) 775
326. Diagram of the Vessels of the Eye. (Leber) 776
327. Meridional Section of the Human Ciliary Body. (Böhm and Davidoff) 777
328. Dissection of the Zonula. (After Schultze) 778
329. Lateral View of the Orbit, Showing the Nerves. (Deaver) 779
330. The Nervous Mechanism of the Iris 780
331. Isolated Lens Fibers. (J. Arnold) 781
332. Transverse Section of Lens Fibers. (J. Arnold) 782
333. Anterior Surface of the Lens of an Adult. (J. Arnold) 782
334. Diagram of the Structure of Human Retina According to Golgi's Method. (Greeff) 783
335. Hexagonal Cells from the Pigment Layer of the Retina of a Rabbit. (Ball). 784
336. Action of the Light on Retina. Section of retina of Frog. (Englemann) 785
337. Right Eye, Normal Fundus Oculi. (Ball) 786
338. Diagram of the Occipital Region of Right Cerebral Hemispheres. (Ball) 787
339. Diagram of the Lymph Spaces of the Eyeball. (After Fuchs) 789
340. Schematic Eye Three Times Natural Size. (Landolt) 790
341. Diagram Illustrating Spherical Aberrations. (Ganot) 794
342. Scheme of Accommodation for Near and Distant Objects. (Landois, after Helmholtz) 795
343. Refraction of Parallel Rays of Light in Emmetropia (*E*), Hypermetropia (*H*), and Myopia (*M*). (Ball) 797
344. Different Kinds of Lenses. (Ganot) 798
345. Refraction of Rays in Regular Astigmatism. (Ball) 798
346. Diagram Showing Refraction by a Double Convex Lens. (Ganot) 799
347. Concave Lens Diverging Parallel Rays of Light. (Lahousse) 799
348. Purkinje-Sanson Images. (Ball) 800
349. Diagram to show the Blind Spot in the Visual Field. (Ball) 800
350. Scheiner's Experiment—an experiment to determine the minimum distance of Distinct Vision 801
351. Diagram to show that the visual angle and size of the retinal image vary with the distance of the object from the eye. (Ball) 801
352. Diagram Showing the Corneal Axis, *U-E*; the Optic Axis, *O-A*; the visual Line, *R-Y*; the Line of Fixation, *R-J*; and the Three Angles. (Ball) .. 802
353. The Horopteric Circle of Müller. (Ball) 803
354. The Visual Angle 804
355. Optogram of the Rabbit's Retina of a Window Four Meters Distant. (Kühne). 804
356. Diagram Illustrating the Decomposition of White Light into the Seven Colors of the Spectrum in Passing Through a Prism. (Beclard) 805
357. Wools for the Detection of Color Blindness. (Oliver) 806
358. Diagram Illustrating Irradiation. (Stirling) 808
359. Diagram to show (1) the primary position of the right eye; (2) the eye turned upward and inward, and (3) downward and outward. (Ball) 808
360. Muscles Associated in Moving the Eyeballs in the Directions Indicated by the Arrows. (Ball) 809
361. Positions of Images in Ocular Paralyses. (Ball) 810
362. Capsule of Tenon. (Ball, after Merkel) 810
363. Diagram Illustrating Binocular Vision. (Beclard) 811
364. Lacrimal and Meibomian Glands, the latter viewed from the posterior surface of the eyelids. The conjunctiva of the upper lid has been partially dissected off, and is raised so as to show the Meibomian glands beneath. (Raymond, after Testut) 812
365. Loring's Ophthalmoscope 813
366. Direct Ophthalmoscopy. (Ball) 814
367. Indirect Ophthalmoscopy. (Ball) 814
368. The McHardy Perimeter. (Brown) 815
369. Diagram of the Normal Visual Field for White and Colors. (Jennings) 816
370. Diagram of the Visual Tract. (Ball) 817
371. Diagram of Right Homonymous Hemianopsia and of the sites of lesions which may cause it. (Ball) 818

FIG. PAGE
372. Position of the Nuclei of the Cranial Nerves. (After EDINGER)................ 822
373. Distribution of the Third and Sixth Nerves in the Orbit. (LEVEILLÉ)....... 824
374. Nuclei of Origin of the Third and Fourth Nerves. (POIRIER and CHARPY).. 826
375. The Origin of the Trigeminal Nerve.. 829
376. Ophthalmic Division of the Fifth Nerve. (LEVEILLÉ).......................... 830
377. Distribution of the Sensory Nerves of the Head, together with the Situation of the Motor Points on the Neck. (LANDOIS)................................ 832
378. Graafian Follicle from Ovary of a New-born Child. (After P. STRASSMAN) 842
379. Human Spermatozoön. (MANTON)... 843
380. Transection of Chick Embryo, Showing the Three Plastodermic Layers. (MANTON) 844
381. Diagram Showing Development of Spermatozoa in a Seminal Tubule. (MCMURRICH 845
382. Schema to Indicate the Process of Maturation of the Spermatozoa. (BOVERI, HOWELL) 846
383. Diagram Showing Essential Facts in the Maturation of the Egg. (WILSON). 846
384. Schema to Indicate Process of Maturation of Ovum. (BOVERI, HOWELL).... 847
385. Schematic Representation of the Process Occurring During Cell-division. (BOVERI, HOWELL) 848
385a. Differentiation of Germ Cells and Somatic Cells. (BOVERI).................... 850
386. Schematic Representation of the Process Occurring During the Fertilization and Subsequent Segmentation of the Ovum. The chromatin (chromosomes) of the ovum is represented in blue, that of the spermatozoön in red. (BOVERI, HOWELL) 852
387. Formation of Decidua (the decidua is colored black, the ovum is represented engaged between two projecting folds of membrane). (After DALTON).... 854
388. Projecting Folds of Membrane Growing Around the Ovum. (After DALTON).. 854
389. Showing Ovum Completely Surrounded by the Decidua Reflexa. (After DALTON) 854
390. Diagram of an Early Stage of a Primate Embryo. (MINOT)..................... 855
391. Uterus at Menstrual Period, Showing Congested Area and Destruction of Mucous Membrane. (Photomicrograph by Gramm.) (GILLIAM)........... 859
392. Virginal Uterus. (GRANDIN and JARMAN) 861
393. Normal Uterine Contraction Effect of Mammary Gland Extract on Uterine Contraction 862
393a. After Effect of $1/4$ Grain of Extract of Mammary Gland......................... 862
393b. Primary Effect of Prostrate on Uterine Contractions.............................. 863
393c. After Effect of Prostate on Uterine Contractions................................. 863
394. The Fœtal Circulation. (GRANDIN and JARMAN)................................ 864

CHAPTER I.

THE CELL.

Observation and experience tell us that all tangible or material things about us are either dead or alive; that is, matter is either lifeless or living.

The conception of life in its simplicity is limited to a few elementary phenomena, such as *nutrition, evolution, reproduction, sensibility,* and *motion.* These properties taken together distinguish the living from every form of lifeless substance. Combinations of these simple, elementary phenomena give us every complex function of our present life. If the study of life is the study of these elementary phenomena, it is necessary that our working force be brought to their seat and home—the cell.

Everywhere there is a sharp line or division between living and lifeless matter, although the two are frequently so closely allied that first observations seem to show *no* distinctions. This is particularly true of those things that are not seen with the naked eye—microscopical things. When one's attention is brought to such objects as quartz, iron, the earthworm, or the dog, the distinction is very evident. On the other hand, long and tireless observation and investigation are required to determine whether some of the bodies found in water are dead or alive. And although so closely associated, scientists have found that a living substance never comes of its own accord from a lifeless one, but only through the influence of some other living matter. For example, no vegetation springs up from the soil until the seed (a form of dormant life) becomes buried in it; no colony appears for the bacteriologist on the sterilized medium until the surface is impregnated with the germ.

Although the sharp distinction exists, nevertheless the two materials are very closely associated, as is shown by a little observation. Plants and animals are kept alive and nourished by the food they consume, and it consists, in the main, of lifeless matter. While in the body it seems to be transformed, as it were, to a living state, and it forms part of the body. After it has served the needs of the economy of the plant or animal it dies, and is gotten rid of as waste-matter.

A living plant or animal is like a fountain *into* which and *out of* which material is constantly passing, but the fountain maintains its form and general appearance. Huxley's simile of a whirlpool in a stream is very striking. The pool remains the same in the stream, but water enters it, becomes a part of it as it is whirled around, then passes out and gives place for other to enter. The pool retains its identity all the while that its elements are being changed.

The contrast between living and lifeless matter forms the basis of the separation of the natural sciences into two divisions: the *biological* and *physical* divisions, biology dealing with living and physics with lifeless matter.

Biology is the science that treats of living things, whether animal or vegetable, normal or abnormal. It deals with the forms, structures, and origin, together with the functions and activities of the whole animal or plant or its various parts. In fact, its scope is so wide and comprehensive that it becomes necessary to divide it into two branches: *morphology* and *physiology*.

Morphology is that part of the science that deals with the form and structure of living things, together with their arrangements.

Physiology is the science that treats of the functions, or work, of the various parts of the living organism, and what each one does toward the economy of the whole. For instance, the study of the form, growth, and development of the different parts of the brain, beginning with the lamper-eel, then the higher fishes, birds, and mammals, belongs to the science of morphology. By comparisons we see that in the lamper there is merely the semblance of a brain in its crudest form, showing no development as compared with the brain of the higher fishes and birds. In the latter we notice a stronger development in one department—the optic lobes. The cerebral portion is very weak. In mammals the reverse is true, and it reaches its most striking size in man, in whom the cerebral portions are extremely large and well developed, while the optic lobes are relatively small.

The study of the functions, for instance, of the heart and kidneys belongs to the science of physiology; which tells how the heart by its alternate contractions and relaxations forces the blood through the circulatory system to the peripheral parts of the body for its sustenance and nutrition and to the lungs for its purification by the elimination of the carbonic acid and the absorption of the oxygen; and how the kidneys by means of their mass of tubes and cells take from the blood those parts that are no longer of any use, fit only to be expelled from the body. When physiology is applied to man, it is called human physiology, for the great and ultimate end and aim of all physiological studies is the understanding of the functions of ourselves. Morphology and physiology are treated as though they were absolutely distinct sciences, yet they are so closely related that the division is made only for convenience.

Morphology includes in its category such subdivisions as *anatomy, histology,* and *embryology.*

Anatomy is the science that treats of the situation, form, and structure of the various parts of the organism. Anatomy from its root keeps in mind the idea of cutting or dissecting, and as commonly used at the present time deals with the grosser work done upon the more common and apparent structures of the body with scalpel and forceps. When we describe in all their detail the different organs of the body and the position of the organs to one another, we call it descriptive anatomy.

Contrasted with anatomy is *histology,* sometimes called microscopical anatomy. Histology is the science that deals with the intimate structure of the various tissues of an organism. It takes up the work where anatomy ends; as it brings to its aid the microscope, it can delve down deeper and deeper until it gives us knowledge of the component parts of the various organs. Histology is a tissue-study. Its separation from anatomy is only for convenience, and is not absolute.

Embryology is the science of the development of the adult from the ovum or germ. It gives a history of the various stages of development from the moment of impregnation of the ovum, until the adult is reached. Its field is more closely associated with morphology than physiology.

Living things are usually found in separate masses and these have peculiarities and structures of their own which give to them the name "organisms." This is true equally of the large masses, such as the elephant or whale, as of the small bodies found in water or the bacteria of disease. All the structures of the latter have as yet not been discovered nor dissected, as it were, since the microscope is not powerful enough and our supply of reagents not adequate enough to lay bare all of their properties and forms.

When we examine some of the contrivances found in the mechanical world, such as a watch or a machine, they at first sight appear to us, as regards their identity, single individual units; that is, as one watch or as one machine, each capable of doing its own peculiar work. Upon closer investigation, we perceive that each is composed of a variety of individual parts, each of which has its own peculiar share of the work to be done and bears an essential relation to the working of the whole. In the watch, the springs, pinions, levers, and numerous little wheels all bear certain relations to one another and assist in the running of the watch.

Similarly we find that it is characteristic of any living body or organism—say, a dog or a rose—that it should be made up of a number of different and distinct parts which are so constructed that they may assist in the life of the whole organism. The animal has a head, a trunk, limbs, eyes, ears, etc., externally; heart, lungs, liver, stomach, intestines, brain, etc., internally. To these parts the name *organs* has been applied. Thus, the organism is composed of distinct parts called organs. The division of the body into organs is purely artificial.

An *organ* is a particular part of the organism that has a certain specified work to do. For example, the liver is a certain structure found in a particular situation in the animal and has assigned as its share of the work of the general economy, the manufacture of the bile to aid digestion. So, also, the eye and the stomach are organs. They are particular parts of the organism concerned in particular work; the eye, in sight, or vision; the stomach, in digestion.

The work that any organ does is called its *function.* Since the appearance and structure of the various organs of a living body are so varied, therefore we do not expect that their functions are any more the same than the functions of the watch and locomotive. Thus, the function of the heart is to pump the blood to all parts of the body; of the blood, to carry nutritious foods to all parts, and at the same time to carry away certain waste-products; of the kidneys, to excrete waste-matters from the blood; of the brain, to have a general oversight and to govern the functions of the whole organism, etc.

Anatomy is the forerunner of physiology and must pave the way for it. For how are we to study the functions of the various organs and their relations to one another, unless we are acquainted with the structure, form, and position in the body of the various organs? Even while studying physiology, anatomy must run hand in hand with it, particularly that modified form of anatomy—histology, or microscopical anatomy—which deals with the minute structures and their components—the cells.

We have learned that the various portions of the living body are called organs. As we know, each organ has its own particular work to do. By careful dissection, we find that an organ—a human arm, for instance—is made up of a variety of substances called *tissues.* There are bone-tissues, cartilaginous tissues, muscle-tissues, nerve-tissues, etc., all different in structure, yet all bundled up in the member called the arm and essential to it to perform its various functions. The brain is composed of two distinct tissues—the gray and white tissues. So, in like manner, any of the organs of the body may be resolved into various parts known as tissues.

Thus far anatomy has aided us in our analysis of the various parts of the body, for it has to deal with only the grosser, coarser, and more obvious forms of the body. So, for a long time, physiology was the study of those large and more evident organs. Physiology could not go further until it had more exact and intimate knowledge of the organs. How can we gain correct knowledge of the working of any machine unless we first know and understand the construction of the parts of the machine?

Chemistry and physics teach us that matter is made up of simple forms, called *elements* and *molecules,* respectively. It is assumed that the units, ultimately, of these elements and molecules are definite, though exceedingly small, material particles. These particles are called *atoms*—the word meaning that the particles are unable to be divided without losing their identity. The atom of the chemist and the cell of the physiologist are the final divisions of matter. In the physical world it was found that all phenomena were due to the movements of these small particles—the atoms.

The fact that animals and plants, although very different externally, are made up of the same anatomical units was not brought to light until the invention of the microscope. These structural units were called *cells.* The theory that organisms were made up of cells was suggested by the study of plant-structure. At the end of the seventeenth century, scientists, by means of their low-power microscopes, discovered in plants small, roomlike spaces, provided with firm walls and filled with a fluid. Because of their similarity to the large cells of the honeycomb these small structures received the name of *cells.* To the scientists, however, the principal feature seemed to be the firm walls. By study, they found that the cell absorbed nutrient material, assimilated it, and produced new material. Although plants were composed of a mass of cells, or even a single cell, it was found that each cell was an isolated whole; that it nourished itself and built itself up. The cell-theory was also applied to animal tissues. By its use it was found that many of the tissues were formed also of cells and that these cells appeared to be of similar construction to those in plant life. Thus we find that every tissue is composed of minute parts known as cells and which in a particular tissue are nearly or quite similar. For instance, in examining a muscular fiber, we find that it is composed of very small, ribbonlike units called muscle-cells. Although differing somewhat in size and development, yet they are otherwise similar; that is, muscular tissue is composed of muscular units, or cells. Cartilage is composed of oystershell-shaped cells; mucous-membrane cells are gobletlike, and secrete, or give off, mucus. Even though these cells are self-supporting and grow and form other cells, in the higher animals they are grouped and held together by means of a kind of cement, spoken of as "intercellular material."

Hence a tissue may be defined as a group of similar cells having a similar function. Tissues are different only because they are composed of different kinds of cells having functions peculiar to themselves. An aggregation of cartilage- and muscle- cells gives us, respectively, cartilage- and muscle- tissues.

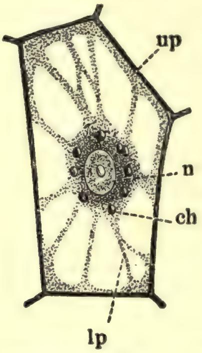

Fig. 1.—Vegetable Cell. (Duval.)

up, Cell-wall of cellulose. *n*, Nucleus. *ch*, Chlorophyll bodies.

As the result of this knowledge, physiology is beginning to develop from a science of the organ and its functions to that of the cell and its functions. But this is only natural as a form of development, since we first consider the greater and more active functions of the organs and then delve down deeper and deeper until we reach the functions of the cell.

Cells are characterized by the presence of the elementary functions or phenomena of nutrition, growth, reproduction, etc. If physiology has to deal with them, it can do it most successfully by studying them in their seat—the *cell.*

The vegetable cell is known from the animal cell by the presence of cellulose.

The cell of the vegetable kingdom in its respiration takes in oxygen and gives off carbonic acid, as we do, but in its nutrition the action of the sun's rays upon the chlorophyll causes it to break up the carbon, to fix it in the tissues, and to give off oxygen. This fixation of carbon overshadows in daylight the ordinary respiration of the plant, which goes on both by day and by night. Yeast-cells break up sugar into alcohol and carbonic acid. Besides this action, they have in them a ferment, invertin, which changes cane-sugar into invert-sugar, which is a mixture of dextrose and lævulose.

CELLS.

We have learned that the higher forms of life, whether plants or animals, may be resolved into a vast number of very small, structural units, called *cells.* The skin, muscles, bone, brain, etc., appear to the naked eye to be composed of one kind of substance respectively. The microscope, however, has told us that each tissue is composed of colonies of units, held together by intercellular cement, and that the units or cells of a particular tissue are similar in structure and functions. For example, upon examination, we find that muscular tissue is made up of ribbonlike fibers, similar in appearance and structure and all engaged in the same function—contraction. Thus, the cell is not only the unit of structure, but also of function, diseased or normal.

Animal cells are of various sizes. Although differing very much in shape and appearance in various parts of the body, nevertheless every cell consists of the following parts: (1) *protoplasm,* (2) *nucleus,* (3) *centrosomes,* and (4) various matters commonly called *"special cell-constituents."*

Max Schultze's definition of a cell, enlarged by later research, is: *"A mass of protoplasm containing a nucleus."*

The term *cell* as employed to-day is a misnomer, but from its constant use since the seventeenth century, it has gained such a hold upon the minds of those engaged in the study of science that the attempt to supersede it with a more appropriate term has been unsuccessful. However, the idea that it originally conveyed has been somewhat modified. The term originated among the botanists of the seventeenth and eighteenth centuries, and was applied to chamberlike elements, separated from one another and containing a fluid. Their characteristic and most important feature was the wall, or membrane, in which were supposed to lie active properties of the cell. The liquid, originally called *plant-slime,* was named *protoplasm* by von Mohl, and was thought to be a waste-product.

That the wall, or membrane, was not of vital importance was clearly demonstrated by later researches. The study of the amœba and of the white blood-corpuscle, one-celled organisms, was the chief means. These organisms are capable of extending their bodies into processes—fine threads and networks—as they move about from place to place, taking up and giving off matter as they go. They possess all the elementary vital functions, and yet at no time do they possess a cell-membrane, showing that the protoplasm, not the membrane, was the seat of the functions. An immense number of other unicellular organisms were examined, together with the development of other plants and animals, and many cells devoid of a membrane were found.

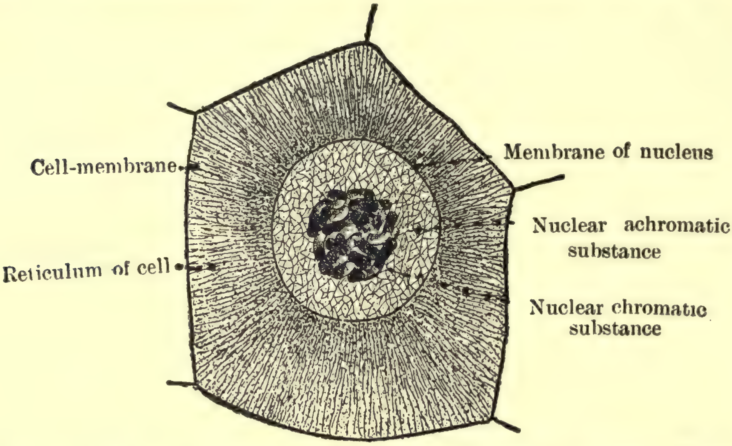

Fig. 2.—Cell with Reticulum of Protoplasm Radially Disposed. From Intestinal Epithelium of a Worm. (Carnoy.)

PROTOPLASM.

The protoplasm of unicellular organisms appears as a viscid substance, which is almost always colorless and which will not mix readily with water. The term protoplasm is constantly in the mouths of the physiologists, and it is difficult to give it a rigid definition, since it is used in so many different senses. Hence, we commonly describe protoplasm as a living substance surrounding a nucleus, which substance may or may not be limited by a cell-wall.

Its refractive power is greater than that of water and in it, as a medium, very delicate threading of protoplasm may be distinguished. It was formerly supposed to be composed of a homogeneous material, and destitute of any structure and to contain a number of minute granules of a solid nature.

Under the high powers of the microscope, when properly stained with reagents, it has been found that the protoplasm consists of two parts: (1) a fine network of fibers, like a sponge, called the *reticulum,* or *spongioplasm;* and (2) the more fluid portion in the meshes, called the *enchylema,* or *hyaloplasm.* However, it must be mentioned that the views concerning the structure of protoplasm differ, several theories being offered. According to the first idea, the protoplasm forms the network, the nodal points of which appear as individual granules. It is very probable that many of the larger and more obvious granules are inert bodies, such as glycogen, mucin, fat-globules, albuminous substances, etc., suspended in the network. The glycogen granules are found in the liver-cells, the fat-globules in the cells of the lacteal glands, and the pigment-granules in the skin-cells of many colored animals. Sometimes, in unicellular animals, calcareous matters are found, although those most uniformly found are of the same general nature as the protoplasm. All these particles, or granules, are termed *microsomes.* Besides, there are

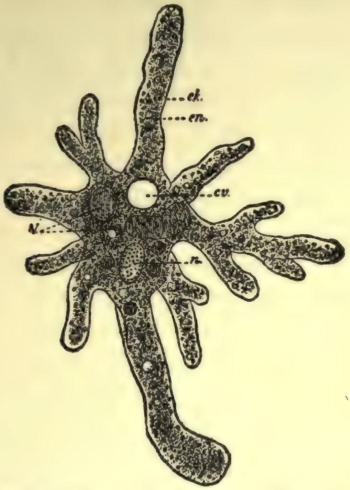

Fig. 3.—Amœba Proteus. (Leidy.)

***n*, Nucleus. *cv*, Contractile vacuole. *N*, Food-vacuoles. *en*, Endoplasm. *ek*, Ectoplasm.**

occasionally found indigestible bodies, such as grains of sand, indigestible residue of foodstuffs, and excretory substances, waiting to be expelled from the body.

Other substances found within the protoplasm and supposed to be of great importance to cell-life are drops of liquid—*vacuoles,* as they are commonly called.

Specific Gravity of Living Protoplasm.

Living protoplasm has the physical property of having a greater specific gravity than water. When cells of the most varied kinds are allowed to fall into water they sink to the bottom. In some cases the protoplasm contains a considerable quantity of fat; so that, although the substratum of protoplasm is heavier than water, the floating of the cell is due to the lighter specific gravity of the fat-particles overcoming the heavier specific gravity of the protoplasm.

The chemical composition of protoplasm (a living substance) can be obtained only after it has been killed. However paradoxical this may seem, it is found impossible to apply the methods of chemistry without killing it. Every reagent that comes in contact with it disturbs and changes it and eventually kills it. Thus, our ideas of the chemical composition of living protoplasms are the ideas we get from the chemical composition of dead protoplasm.

The substances of which it is composed are:—

1. **Water.**—Water is that element in a living substance that gives it its liquid nature, allowing its particles to move about with a certain degree of freedom. In the cell, water occurs, either chemically combined with other constituents or in the free state. Salts occur dissolved in the water. Protoplasm is semifluid, and about three-fourths of its weight is due to water. The molecules of protoplasm are thought to be separated from one another by layers of water.

2. **Proteids.**—The proteids take a very active and essential part in the functions of all cells. The proteids consist of the elements carbon, hydrogen, sulphur, nitrogen, and oxygen. Proteids occur both in the protoplasm and in the nucleus, but with this difference: that found in the nucleus has combined with it phosphoric acid, forming the so-called nucleins. To show this fact is very easy, for the nuclein of cells resists the action of digestion by the gastric juice. All kinds of cells in artificial gastric juice have their protoplasm digested and only the nuclei remain; that is, nuclein. If, now, this nucleus is treated with stains, it shows that the nuclear bodies consist

of nuclein, while the protoplasm of the cell is constructed from other albuminous bodies.

Protoplasm is composed principally, then, of simple proteids and compound proteids that lack phosphorus. Our most common and typical type of an albuminous substance, or proteid, is the white of an egg. This contains 12 per cent. of actual proteid substance, the remainder being chiefly water. The albumins are the only bodies that can safely be said to be found in all cells. Although the albumins contain only five elements,—C, H, N, S, and O,—yet the number of their atoms often exceeds a thousand.

3. Various Other Substances occur in smaller proportions as *carbohydrates;* as glycogen in protoplasm of liver-cells; *fats,* seen in protoplasm as fats or oil-drops; and *simpler substances* which are the result of decomposition of the proteids, or are concerned in its formation; and also, *inorganic salts,* such as phosphates, and chlorides of calcium, sodium, and potassium.

NUCLEUS.

From an examination of the protoplasm, we pass on to the nucleus. As we have said before, "a cell is a mass of protoplasm containing a nucleus." Various properties and functions of an important nature have been assigned to protoplasm, but it is found that the nucleus is equally as important. The classical experiments of the old observers upon protoplasm led them to believe that the protoplasm was the embodiment of all the functions of life. To them the nucleus was unessential as regards the activities of life. The ruling power of the protoplasm was dismissed when it was found that the nucleus in reproduction of cells by division or impregnation underwent extraordinary changes, while the protoplasm remained passive and quiet. Within recent years there has set in a reaction, and the happy mean 'twixt the two extremes is now held to be correct: the two are of equal importance.

By extended research and with staining reagents such as carmin, hæmatoxylin, etc., a distinct nucleus was found imbedded in the protoplasm of most animal cells. For a long time, and until the microscope was greatly improved, two classes of organisms appeared to be the exceptions. They were, *monera,* the lowest and simplest organisms, and *bacteria.* Gradually the number of each class was reduced until at the present day it may safely be said that *every cell contains a distinct nucleus.* Every cell may thus be said to be characterized by *two* general cell-constituents, protoplasm, and at least one nucleus.

The *form* of the nucleus is different in various cells. Usually it is a round or oval body situated in the middle of the cell. Its rounded form is considerably expanded in young cells, as in the ovaries in their evolution. Very frequently the form of the element influences that of the nucleus. Thus, in muscle- and nerve- cells the nucleus is generally elongated. In the lower organisms it sometimes assumes the shape of a horseshoe or a twisted strand, or is very much branched, the processes running out in every direction into the surrounding protoplasm.

The *size* of the nucleus is usually in proportion to the mass of protoplasm enveloping it. Thus, in the large ganglion-cells of the spinal cord the nuclei are correspondingly large. Also in cells engaged in active work, the nuclei are generally of good size, as in the secreting cells of the salivary and mucous glands.

As to the *number* of nuclei present in a cell, the general condition of the presence of but one in a cell seems to prevail. There are exceptions, however, as liver-cells very frequently contain two, and the immense cells of bone-marrow, many.

General Substance, or Structure.

The nucleus is no more of a homogeneous nature than the protoplasm and presents several distinct substances and structures. The different constituents that are known are not always present in all cells, at all times, or in the same proportions. Among some cells one element may be very conspicuous, while in some others it is scarcely to be found. According to Verworn, the following substances occur most constantly: (1) *nuclear sap,* (2) *achromatic nuclear substance,* (3) *chromatic nuclear substance,* and (4) the *nucleolus.*

The *nuclear sap* may be present in larger or smaller quantities and is the liquid ground-substance which fills up the interstices left among the solid nuclear constituents. In many cells under the influence of certain reagents, and even in life, it is known to be of a very fine granular nature.

The achromatic nuclear substance is a structure of fine threads found in the nuclear sap, and it is characterized, as is also the latter, by not staining with the usual reagents; carmin, hæmatoxylin, etc. It contains achromatin or linin.

Lantanin is found in linin in the form of fine granules, which stain by acid anilin dyes, as opposed to chromatin, which takes up only basic anilin dyes. Hence lantanin is called oxychromatin, whilst chromatin is known as basichromatin.

The *chromatic nuclear substance,* as its name implies, has an affinity for coloring-matter in the form of different stains. It is usually in the form of a continuous network, but sometimes appears in small granules, or particles. It contains chromatin or nuclein.

The *nucleolus,* if it appears at all, is found in the network of the nucleus, as a rounded or irregularly shaped body. It contains paranuclein or pyrenin and has an especial affinity for color, and stains more deeply than the network. The nucleoli are thought to be *passive* bodies that hold in reserve different constituents which are essential to the life of the nucleus.

Sometimes the nucleus is enveloped in a membrane, called the *nuclear membrane,* which marks it distinctly from the protoplasm. This, however, as with the *cell-membrane,* is not universal and is not classed as a general constituent of the nucleus. The sharpness of the contour which distinguishes the nucleus in the midst of protoplasm led many histologists firmly to believe that the nucleus always does possess a membrane. The truth is between the two extreme opinions. The nucleus can very readily exist without one.

The nuclear membrane consists of an achromatic substance, amphipyrenin.

A portion of a cell deprived of its nucleus may live for a time, but it evinces no activities or functions other than that of movement. It neither absorbs food, nor grows, nor reproduces, but seems gradually to dwindle away and die. From this it is believed that the nucleus exercises some powers with regard to the building up, or constructive metamorphosis.

Regarded *chemically,* the nucleus is composed principally of proteid and a substance like proteid, which contains as much as 10 per cent. of phosphorus. No doubt there are others, but even the most delicate chemical reagents kill the constituents and so lessen the opportunities for careful investigation.

CENTROSOME.

About twenty years ago, when nuclear cell-division was being investigated, a small body other than the nucleus was noticed during the division of the cell and was called by various names: *polar corpuscle, central corpuscle,* or *centrosome.* The last name seems to be more generally used at the present time.

The *centrosome* in its simplest form is a body of extreme minuteness, frequently not larger than a microsome, but which exerts an active influence on the protoplasmic structure during cell-division.

Because of its influence in the cell, it has aroused more interest among investigators than any other component of the cell. By some it is considered to be a part of the nucleus, and by others, of the protoplasm. As a rule, it lies in the protoplasm just outside of the nucleus, even during the resting stage, and in certain conditions of the cell is clearly indicated by a radiation of protoplasm, attraction sphere, or archoplasm, the fibers of which are arranged in the form of a star, the centrosome being at the center.

In *size* the centrosome ranges between that of the ordinary microsome and the smallest micro-organism. No structure has been as yet discovered in it. It cannot be classed as a general cell-constituent, since many forms of the cell and unicellular organisms have been examined and no centrosome found, due probably to the inadequacy of the microscope. Most authors consider the centrosome as an essential part of the cell.

The centrosome does not absorb the ordinary stains suitable for the nucleus, but requires acid anilin dyes, as acid fuchsin and orange. By them it is colored vividly.

As a rule, there is one centrosome in a cell, lying close to the nucleus and surrounded by a raylike or rodlike structure of the protoplasm. As the cell prepares for division, the centrosome divides into two distinct parts, both lying passively within the starlike network. When the daughter-cells are examined, each is found to possess one of the centrosomes, which, as the cell grows, passes through the same process as its antecedents. The centrosome is regarded as the particular organ of cell-division.

PROTOPLASMIC MOVEMENT.

The movements of protoplasm are movements in currents and the amœboid movement. In certain vegetable cells protoplasm moves and causes a true rotation of its substance, as in Chara; or the movement may be in opposite direction and the paths even cross over each other. In this movement all parts of the protoplasm do not move with the same rapidity. The rate in protoplasm is about $^1/_{50}$ inch per minute.

Movements differ according to whether the protoplasm is *naked* —without any enveloping membrane—or *inclosed within a firm wall, or membrane.*

1. Movement of the Naked Protoplasm.

Probably our most common and typical form of naked protoplasm is presented to us by the fresh-water *amœba,* found in stagnant water. The amœba is a unicellular organism, about $^1/_{1000}$ inch in diameter, possessing one or more nuclei, and is almost continually in motion, due to its extending numerous protoplasmic projections, called *pseudopodia* (false feet). It then rolls its entire mass into the pseudopodium, or fingerlike projection, only to continue the same operation repeatedly during its life.

The pseudopodia assume different forms and shapes in the different kinds of cells, and in this way the establishment of the identity of a cell is frequently aided by an observation of the processes. For example, most of the fresh-water amœba possess broad, lobate or finger-shaped pseudopodia; leucocytes, white blood-corpuscles, divided and pointed pseudopodia; some of the rhizopods and pigment-cells, threadlike and reticular pseudopodia which flow into one another.

In the human body some of the cells—such as white blood-corpuscles, lymph-corpuscles, and connective-tissue cells—possess movements, which, because of their likeness to those of the amœba, are called *amœboid.*

2. Ciliary Movement.

There have been discovered cells and unicellular organisms possessing delicate, hairlike processes, which extend in greater or less numbers from their surfaces. They are called *flagella,* or *cilia.* These resemble very thin pseudopodia when they are composed of hyaloplasm alone, as the cilia and flagella are homogeneous and nongranular in nature. However, they differ from pseudopodia in that their movements are very energetic and always definite, and also that, unlike pseudopodia, their structures are not temporary, but permanent, being neither protruded nor withdrawn. The ciliary cells lining the trachea are subjects for examination. The deep back part of the throat of a frog is gently scraped and the scrapings placed in a drop of water upon a warm stage. When we examine the cells under the microscope, we see upon their surface a constant rapid movement; but the movement is so rapid that we see only the motion, and not the vibrating cilia. If, however, the vibrations be lowered to about a dozen per second, we are then able to see the cilia themselves. Ciliary movements are of various kinds. More frequently it is a movement of elevation and depression of the cilia; sometimes it is like the extension and flexion of our fingers, at other times a sort of wave or whirlpool-like movement. In these movements all the cilia on the surface move in the same direction, like a field of grain before the wind. Each completed movement of the cilia is composed of two movements of unequal duration, the longer corresponding to contraction, and the shorter to relaxation of the cilia. Ciliary movements may be of a high rapidity, as many as 960 to about 1000 per minute, and entirely independent of the circulation and the nervous system. These movements are able to continue after death as long as a day, while in frogs they have been observed for many days.

Cilia are about $^1/_{3000}$ inch in length and are able to perform some work. By their movements they are able to float a cell in a liquid, such as water, even though the cell and cilia are composed, in a great part, of protoplasm, whose specific gravity is heavier than water and naturally inclined to sink, and at the same time they propel the cell in some definite direction at a much faster speed than that obtained by the protrusion and retraction of pseudopodia. The function of the ciliated cells does not appear to be of any particular importance in man except that in the trachea their movements bring to the larynx foreign substances that have been inhaled into the lungs, such as dust, etc., and to bring up for expectoration the thickened mucus that is formed during the stages of a cold.

A practical illustration of the effects of the protoplasmic movements of leucocytes (white blood-corpuscles) can be observed when an injury occurs to any part of the body. As a result of the injury and as an attempt at repair, more blood is sent to the injured part. This result, called congestion, gives to it its red color. With the additional quantity of blood comes an additional number of leucocytes. They, by protoplasmic movements, pass through the walls of the capillaries to the seat of the injury, to take up dead portions. Sometimes bacteria lodge in the wound, which the leucocytes approach and kill by ingestion, as it were, thus rendering them harmless. This process of ingesting bacteria and other foreign substances is called *phagocytosis,* and hence the leucocytes are sometimes termed *phagocytes.*

The phenomenon of a leucocyte in active movement, which by one-sided action of the chemical products of bacteria, as toxins, moves toward (positive) or away (negative) from the bacteria, is called chemotaxis.

CELL-DIVISION.

We have learned that organs are composed of various structures, called tissues. A tissue may be defined as "a group of similar cells having similar functions." For example, muscular tissue is made up of ribbonlike muscle-cells; mucous tissue of secreting, goblet-shaped cells; nervous tissue of ganglion-cells, with their numerous projecting dendrons, etc.

By observation we notice a variety of tissues due to a variety of kinds of cells; also that all tissues of a kind are not necessarily of the same bulk, size, or weight.

The chick contains, in its body, a number of organs of a definite size and consistency. It has a head, limbs, muscles, a heart, lungs, intestines, a liver, etc. We see, of course, that these organs are of a size and weight in proportion to their age—none of them large or heavy. Upon examination, we find the tissues of the various organs to be composed of cells such as we should expect them to contain; that is, the muscles of muscle-cells, the bones of osseous cells, the brain of ganglion-cells, etc. Furthermore, although cells are of different sizes and forms, yet there is very little difference in respect to size between the cells of a particular tissue, as compared with one another, or with those of the adult animal; for the size of every cell is definite.

When we observe the same animal one year after its birth, we notice some striking differences: it is much larger and heavier, the various organs are fuller, more compact, and show the effects of the development as it approached maturity. The head, brain, muscles, heart, lungs, intestines, etc., are all much larger and better developed than those found in the small chick. However, if a microscopical examination be made of the various tissues in this, the adult animal, what do we find and how do the cells compare with those of the chick? Nothing remarkable in the individual cells themselves. The liver-cells of the adult are no larger than those of the chick, nor are the ganglion-, muscle-, or other cells. What we do perceive is a great increase in the *number* of the cells in any particular tissue. The liver and brain of the adult animal contain many more cells than the same organs of the chick. Thus we see that there has been a growth due, not to larger cells, but to a greater *number* of cells. That is, the cells have multiplied.

Similarly, as the infant passes through the various stages of boyhood, youth, and manhood, we say that he grows, for there is an increase in the size and weight of the various organs of his body. This means that there is a greater number of cells composing the tissues of his various organs. The power to multiply—that is, producing new forms similar to itself—is one of the most important and characteristic functions of the cell. By this attribute, it not only is able to maintain its own particular kind, or species, but can undergo constructive metamorphosis: building up, or growing, until any part, or organ, is matured.

A cell multiplies by dividing into two or more parts. Each part is, of course, smaller than the original or mother-cell, but, by assimilating nutrient material from the surrounding tissues, it grows until each part is the size of the mother-cell, when it also is ready for division, or reproduction.

No cell exists that has not had its origin in some pre-existing cell. In animals whose tissues are composed of many cells, these same tissues can be traced back to single cells, of which they are developments. The animal itself, with all its many and various parts and structures, originated from a single cell, the germ-cell, or ovum, which have existed in the parent-body, is also derived from a cell.

Schleiden, the botanist and accredited discoverer of the cell-theory among plants, and Schwann, to whom Schleiden confided his views and ideas of plant-structure, and who then reduced animal tissues to their structural units, the cells, were anxious to know the origin of the cells. To them the presence of the nucleus was known, and even the nucleolus; but their instruments were not powerful enough to allow of their penetrating deeper, and of getting the correct ideas of cell-division.

It was proved in 1858 that cells multiplied as a result of the division of the two equally essential parts of the cell, the nucleus and protoplasm. Our present conception, that the two are of equal importance and value, dates from this time. It was asserted that the division began within and proceeded to the outer parts of the cell. That is, the nucleolus was divided, its division was followed by separation of the nucleus, and this, in turn, followed by constriction and division of the protoplasm with its enveloping membrane. These views were confirmed by Virchow, who formulated the doctrine *"Omnis cellula e cellula"* (every cell from a cell).

Later, it was discovered, by the investigation of some of the tissue-cells, that the process of division was not so simple as expected. In some cases, it was found that the nucleus became star-shaped, or lobed, or even seemed to disappear altogether before cell-division. A few years later, it was seen that the process of division was complicated in the extreme, and that the cell-nucleus underwent a variety of transformations, assuming different shapes and figures until two daughter-cells were formed from the mother-cell. This process was afterward named *karyokinesis.*

By experiment, it was demonstrated that, if a cell in a living organism or tissue was so divided that one of the parts was composed of protoplasm only, none of the nucleus being present, the protoplasmic part continued to live for a considerable time, but that, of the vital phenomena exhibited by the normal cell, it possessed only that of movement. It was unable to take up from the surrounding tissues a proper amount of nutrition, so that growth and reproduction never occurred, and after a time it died. Thus it was concerned only in destructive, not constructive, metamorphosis. It was totally unable to build itself up, to grow, or reproduce others of its species. On the other hand, the part containing the nucleus grew and reproduced its kind, forming daughter-cells, that in turn formed other cells, etc.

Thus, in order that the daughter-cell may possess the same properties, form, and functions of the mother-cell,—in a word, in order that it may *live,*—it becomes necessary, in the division, that both the nucleus and the protoplasm must divide. The disposition of any cell to divide, or reproduce, is usually announced by changes in its nucleus, both physical and chemical. In fact, the division of any cell is preceded by division of the nucleus. This process in the cells of most organisms is very complicated, whereas the division of the protoplasm is most simple, consisting of the appearance of a constriction, which becomes deeper and deeper, forming a groove, or fissure, until eventually the mass is divided into two parts.

The evident importance of the relation of the nucleus to cell-division has led to extended study of the nucleus and its transformations during the process of reproduction, with the result that, upon its function in this respect, *three* forms of division are recognized: (1) *direct cell-division,* (2) *indirect cell-division,* and (3) *endogenous nuclear multiplication.*

1. Direct Cell-division (Amitosis).

Direct cell-division is very rare, and present only in *some* of the unicellular organisms and leucocytes. In pathological formations, however, such as tumors, this form of division occurs very frequently.

To get a better conception of the direct form of division, we will study one of the infusorians, the typical amœba, and the changes occurring in it during reproduction. The first intimation of a division is noted in the spherical nucleus, which becomes elongated, the middle portion of it being indented by a constriction, which gives to the nucleus a dumb-bell shape. The constricted portion becomes gradually narrower and slenderer until the two heads of the ball separate and each assumes the same shape as its mother—spherical. The cell thus contains two distinct nuclei. Following the division of the nucleus is that of the protoplasm by constriction also. The indentation always appears between the two nuclei. Eventually two cells are thus formed, each with a separate nucleus; each daughter-cell is, of course, smaller than its mother, but by the assimilation of the nutrient material surrounding it, it soon grows to the normal, definite size. This process often requires several hours for its completion, the various stages being frequently accomplished in an uncertain manner.

2. Indirect Cell-division (Mitosis, or Karyokinesis).

By far the greater number of animal- and plant- cells follow the more complicated and intricate method of *indirect,* or *karyokinetic,* form of division. The division of the protoplasm is simple enough, following only the laws of constriction until the mass is completely separated into two parts, by means of a furrow, or fissure. It is the nucleus which undergoes very remarkable and typical changes, very complicated in their nature, but which in plants and animals are constant and *agree* very much in regard to essentials. Thus the indirect method is very nearly, though not quite, *universal.*

As a cell prepares for division the most evident and important fact noticed is a change in its nucleus, both physical and chemical. The nucleus becomes somewhat enlarged, and its chromatic nuclear substance, or chromoplasm,—so called because it has an affinity for stains,—begins to become changed little by little, from the netlike arrangements of its minute granules and particles, until the substance is arranged in the form of threads loosely rolled up, like a coil or convolution, called the *skein* or *spirem.* These consist principally of nuclein, and stain more deeply than the surrounding parts, and are, hence, more easily discerned. It is the presence of these threads that gives to the process the name *mitosis.* In most cases there is but a single thread, which is coiled or convoluted throughout its entire length; occasionally, there occur several such threads. The threads are somewhat thicker than before, and more separated than during the resting stage. With the formation of the spirem, or wreath, the nucleoli and membrane, if any, disappear. In some cases the nucleoli are dissolved and cast into the hyaloplasm, where they degenerate and have no further function.

The thread of the spirem becomes divided transversely into nearly equal parts, or bodies, known as *chromosomes*, which, in most cases, are in the form of rods, straight or curved. The ground-substance of the nucleus now becomes a part of the surrounding hyaloplasm. The chromosomes at first are placed rather irregularly, but they soon begin to arrange themselves into a more definite form, that of a *rosette.* The curved chromosomes now become more angular and V-shaped, the angle pointing toward the center of the nuclear space while the free ends are directed toward the circumference, this figure being called the *aster,* or garland. While in the form of the aster each chromosome splits longitudinally into halves, so that we have just again as many, though thinner, chromosomes.

Before the membrane has been dissolved, there appear in the protoplasm, but very near the nuclear membrane, two small granules lying side by side. These are the *centrosomes.* They are of a substance that stains with difficulty. Gradually they begin to separate from one another, moving in a semicircle, until they are diametrically opposite one another, or at the nuclear poles. While they have been in motion, the nuclear membrane has been dissolving, so that, by the time they are again at rest, the membrane has disappeared. The *achromatic* nuclear spindle develops between the centrosomes. When they begin to separate, the spindle is small, scarcely discernible, and like a band in form. As the centrosomes separate more widely, the fibers become more plainly visible and assume the form of a spindle—broad in the middle and converging at either end, toward and ending in the centrosomes. The protoplasm now arranges itself around the centrosomes in the form of rays of a star, as though the filaments of protoplasm were attracted by the centrosomes in the manner of iron filings by a magnet. At first these fibers are small, but increase in length and numbers as the division of the cell progresses, until they run throughout the entire protoplasmic mass.

The V-shaped filaments, called chromosomes, are now collected in the plane of the equator, called the *equatorial plate.* While the chromosomes have been arranging themselves in the plane of this plate, they have been growing somewhat shorter and thicker, their angles pointing to the axis of the spindle and their ends to the circumference. By the contraction of the spindle fibers the daughter-chromosomes (the result of the original chromosomes being divided longitudinally into two separate halves by means of fission) are divided into two equal groups, which are moved toward the points, or poles, of the spindle, but never reach it absolutely. Between these groups fine "connecting fibrils" stretch. This figure is called the double star, or *diaster*. The star shape is formed by the angles of the chromosomes being arranged next to the centrosomes, with their free ends extending out radially.

There now follows a retransforming of the daughter-chromosomes, arranged in the form of a star, into a genuine resting nucleus. The angles begin to disappear, the threads draw more closely to one another, becoming more bent and roughened at the same time that little processes appear on their surfaces. A very delicate nuclear membrane develops and surrounds the group of threads. The radiating fibers of protoplasm around the centrosomes become more and more indistinct until they finally disappear. The same thing occurs with the "connecting fibrils."

When the two daughter-stars are separated as far as possible there appears on the surface of the *cell-body* a fissure, cutting into the protoplasm in the line of the equatorial plate, until the cell is completely divided into two parts, each containing a nucleus.

The duration of this process has been seen in *man to be half an hour,* while in *the larvæ* of the *salamander* it has been known to take as long as *five hours.*

The whole process of mitosis may be divided into five stages:—

1. Prophase (skein stage).
2. Mother-star stage (monaster).
3. Metaphase-Metakinesis (diaster).
4. Anaphase (daughter skeins).
5. Telophase (daughter nuclei).

3. Endogenous Nuclear Multiplication.

A third rare mode of nuclear multiplication, to which is given the above-named title, was discovered in the thalassicola.

The thalassicola, which is the largest in size of the radiolarians and the diameter of whose central capsule is nearly equal to that of the frog's egg, has, during the major portion of its life, *one single, highly differentiated, giant nucleus,* called the *internal vesicle.* This nucleus, or internal vesicle, usually attains to $^1/_{50}$ inch in diameter, and possesses a thick, porous, nuclear membrane. It is very similar to the multinucleated germinal vesicle of the ovum of an amphibian.

Simultaneously with the advent of the centrosome into the protoplasm, there appeared in the latter, which heretofore has been entirely free and clear, a large number of very small nuclei. These act as centers, around each one of which there develop nucleated zoöspores, which may amount finally to as many as some hundreds of thousands of separate cells.

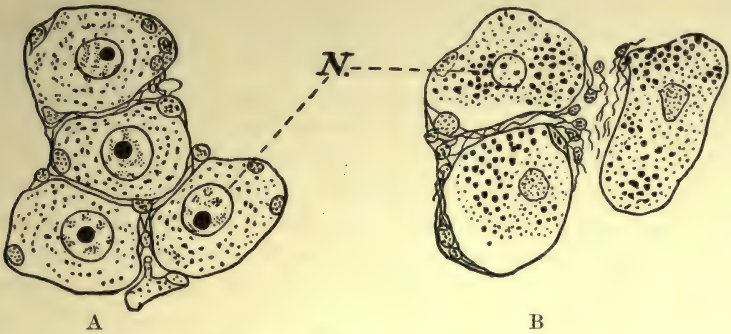

Fig. 4.—To Show the Changes in the Nerve-cell Due to Age. (From Howell.)

A, Spinal ganglion cell of a still-born child. *B*, Spinal ganglion cell of a man dying at 92 years of age. *N*, Nuclei. In the old man the cells are not large, cytoplasm is pigmented, the nucleus is small and the nucleolus much shrunken or absent. Both sections taken from the cervical ganglion. 250 diameters. (Hodge.)

Fatigue of Cells.—Hodge, of Clark University, has found changes in the cell corresponding to rest or activity. Thus the nerve-cell in the morning has a clear, round nucleus, while in the evening, being tired from work, the nucleus has an irregular contour.

Literature Consulted.

Verworn, "General Physiology," 1899.
Hertwig, "The Cell," 1895.

CHAPTER II.

(a) CHEMICAL CONSTITUENTS OF BODY AND FOOD.
(b) ALIMENTARY SUBSTANCES.

Digestion has been described as the physical and chemical alteration of the foodstuffs into forms better fitted for absorption by the action of certain soluble ferments, the digestive enzymes.

The animal organism had its birth in a single ovum or cell, which, under certain favoring circumstances and conditions, developed into a mass of simple cells. As development proceeded, this aggregation became differentiated into tissues, by the grouping of the cells, altered by chemical changes in the substance of the cells themselves, by alterations in their shapes, and by deposits of intercellular substances. As the organism continued to grow, the various parts became more and more complex by use and development until it presented a highly complex unit.

In the metabolism of the cell it was learned that the various cells while performing their various vital phenomena must constantly maintain a very nice balance in respect to waste and repair. That is, the various kinds of cells took out from their environments those substances that were necessary for their economy to build themselves up and grow, while the waste-products were excreted. A distinctive property of the cells was the selective power exercised in regard to different nutrient materials with which they came into contact. Although the surrounding media might contain many kinds of food, yet cells of a particular kind took only that for themselves which was best adapted to their wants, disregarding entirely all the others. As there was a great variety of cells, there must necessarily be a corresponding variety of foodstuffs.

What is true of the cells is true of that of which they are but components or units: the body. Among the phenomena produced by the waste of the solid constituents of the body and the loss of the fluid or watery parts of the tissues are the sensations of hunger and thirst. These sensations of appetite excite the desire to take food, which by the processes of digestion is prepared for absorption and circulation in the blood, to supply the various needs of the organism.

The term food includes all those substances received into the alimentary canal and used for the support of life, by supplying the waste continually occurring in the living animal tissues, and also weight, heat, and energy. Food contains substances that have a certain chemical relation to the tissues which it supports. The substances out of which the complex adult tissues are constructed are *chemical elements, chemical compounds,* or *unions* of these elements. The food taken in by the animal consists of the same or similar composition, in its nature very complex.

Animals are either carnivorous or herbivorous. The carnivora, or flesh-eating species, consume food possessing apparently the same chemical components as the tissues and fluids of their own bodies. The food of the herbivora, or vegetable-eating species, contains principles resembling very closely those found in the animal body. No matter what the source or nature of the food for animals might be, their chemical constituents or principles are similar, since it is through the agency of the vegetable kingdom with the aid of light and heat from the sun that the simpler combinations of inorganic nature are woven together and elaborated to form the complex organisms in the shape of plants and vegetables. Thus, the animal kingdom is dependent on the vegetable for its existence; numerous experiments have proven that the animal organism does not possess the power to any great extent of constructing complex from simple materials. Yet complex foods it must have to supply its own complex constituents. However, it is also necessary that the food should possess, besides the complex constituents, a proper proportion of the various principles, and these must be in a digestible form. It is well known that beans, peas, and other vegetables contain a very considerable percentage of proteid, but it is in such indigestible form, that much of it passes off in the fæces. The various digestive juices had been unable properly to dissolve their nutritive elements.

Of the 80 elements known to the chemist, but 20 are found in the body. They are: carbon, hydrogen, nitrogen, oxygen, sulphur, phosphorus, fluorin, chlorine, iodine, silicon, sodium, potassium, calcium, ammonium, magnesium, lithium, iron, and occasionally manganese, copper, and lead. These elements are rarely found in the free state, being usually in the form of compounds.

The *compounds*, or, as they are sometimes termed, *proximate principles*, are divided into: (1) *mineral,* or *inorganic*, compounds; (2) *organic compounds*, or compounds of carbon. The organic compounds may again be divided very conveniently into two groups: the *nitrogenous* and *nonnitrogenous.*

The *inorganic* compounds are water; the various acids, such as the hydrochloric acid of the gastric juice; and numerous salts.

Since the proximate principles of both food and the body are the same, mention of the principles will be known to refer to both. A very convenient method of grouping the principles of both food and the body is that by Halliburton, as follows:—

Inorganic......	*Water.*
	Salts, as chlorides and phosphates of sodium and calcium.
Nitrogenous....	*Proteids:* albumin, myosin, etc.
	Albuminoids: gelatin, keratin, etc.
	Simpler nitrogenous bodies: lecithin, urea, etc.
Nonnitrogenous	*Fats:* butter, adipose tissue.
	Carbohydrates: sugar, starch.
	Simple organic bodies: alcohol, lactic acid.

Although all of these elements are present, yet not all are of equal importance or occur in the same proportions. Among the inorganic group, *water* and *salts* are prominent; among the organic, *carbohydrates, fats,* and *proteids.*

WATER.

Water forms more than one-half of the body-weight. The value of water to the economy can be readily appreciated by the student when he considers that the various processes and stages of digestion, absorption, and assimilation are dependent upon hydration and dehydration. About fifty ounces of urine are excreted daily, this being the main avenue for the escape of watery elements from the body. In addition, considerable water is given off by the skin as sensible and insensible perspiration, while expired air is heavily laden with moisture.

With so much water making its escape from the body, at least as much must find its way into the economy. About two and a half quarts of water are ingested daily as food. The water we drink ought to be fresh, limpid, without smell, and of an agreeable taste. When complete and exact analysis is impossible, the taste is the only safe criterion or judge as to its fitness. Drinking-water should always contain a certain percentage of air. The palatability is due to the presence of carbonic acid gas in the water. Besides gaseous constituents, solid substances are also present. These are both mineral and organic, and should be present in but very small amount.

Somewhat more water is excreted daily than is ingested, since some water is formed in the tissues by the oxidation of hydrogen.

SALTS.

The most important salts found are the sulphates and chlorides of sodium; the phosphates of sodium, potassium, calcium, and magnesium; and the carbonates of sodium and calcium.

Of these various salts, *sodium chloride* is the most important and the most common one found. In the fluids—blood, serum, lymph, and urine—this salt is high in percentage. While in the body it favors absorption by increasing the endosmosis of the tissues and so aids metabolic processes, the absence of sodium chloride for an extended time causes disturbances and disorders in the constitution. There are about 3000 grains of common salt present in the body. About 180 grains are excreted daily in the urine, while some finds its exit as a component of the fæces, sweat, and tears.

A practical illustration of its value to animal life may be gained by noticing how wild animals repair to the so-called "salt licks" at various times, traveling for many miles to procure it.

The Africans in the interior of their country do not have $NaCl$, but use the ashes of certain plants. These ashes chiefly contain KCl and K_2SO_4 and one-twentieth per cent. of sodium salts.

Calcium phosphate is a very prominent factor of the mineral solids of the body. It forms about one-half of the bony skeleton, where it is most abundant, although it occurs to some extent in all other solids and fluids. This salt is particularly conspicuous in milk.

Iron is an important element of hæmoglobin. It is this iron in the red blood-corpuscles that is the means of holding the oxygen without being itself oxidized. A want of it causes the pathological condition called anæmia. In the blood of an adult are found forty-five grains. In small proportions it is found in the liquids of the body,—as the chyle, lymph, bile, urine, etc.,—in the fæces, and traces in the liver and spleen.

I. CARBOHYDRATES.

The carbohydrates are found principally in the vegetable kingdom. They are, however, not indigenous to the vegetable kingdom, but are found and formed in animal tissues; notably, glycogen, or animal starch; dextrose; and lactose, or milk-sugar.

For the sake of a clearer conception of the term carbohydrate the components of the name are used when it is defined as a compound of carbon, hydrogen, and oxygen, the last two in the proportion occurring in the formation of water, two to one.

The carbohydrates are:—

Glucoses ($C_6H_{12}O_6$), or monosaccharides.
Saccharoses ($C_{12}H_{22}O_{11}$), or disaccharides.
Amyloses ($C_6H_{10}O_5$), or polysaccharides.

The Glucoses are glucose; or dextrose, or grape-sugar; lævulose, and galactose. The glucoses have three properties which are important for the physiologist to know: physical, chemical, and biological. From the fact that it deviates the plane of polarization to the right, its physical property is demonstrated, whence its name, dextrose. Its chemical property is the reducing of certain metallic salts in the presence of alkalies. Biologically, it ferments under the influence of the zymase of yeast to form carbonic acid and ethylic alcohol. The zymase, an intracellular ferment, is formed in the body of the cell.

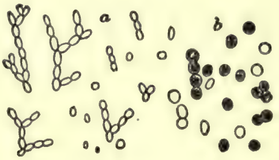

Fig. 5.—Yeast Fungus. (After HARLEY.)

Saccharoses.—The saccharoses are saccharose, or cane-sugar; lactose, or milk-sugar; and maltose. When saccharose, or cane-sugar, is boiled with a dilute mineral acid, the right-handed polarizing solution of saccharose is transformed into invert-sugar, or is said to be inverted. Invert-sugar is a mixture of equal weights of glucose, a right-handed polarizing agent, and lævulose, which is a left-handed polarizing body. The saccharoses do not reduce the copper salts. The saccharoses are not directly fermentable by yeast except in this way: (1) when yeast is added, the saccharoses take up water and the soluble ferment of yeast, *invertin,* changes the saccharoses into glucose and lævulose; then (2) the zymase fermentation of the glucose and lævulose by the yeast-cell, which is not a vital act.

Lactose, or sugar of milk, is a right-handed polarizing sugar. It reduces the copper salts, but is not fermentable either directly or indirectly by the yeast-ferment. Lactose ferments in the presence of the lactic acid bacillus to form lactic acid.

Maltose is a right-hand polarizing sugar, reduces copper salts, and ferments by yeast. Maltose has the same properties as glucose, but is distinguished in two ways: (1) the light-rotating power of glucose is 56 degrees, while maltose is 150 degrees; (2) the reducing of metallic salts by glucose is equal to 100, while that of maltose is but 66. The sugar in blood is a glucose.

By moistening barley and germinating it in heaps at a constant temperature, the starch of the barley is converted into dextrose and maltose. This change is brought about by the ferment called diastase, which is found in barley. This product, when dried, is denominated malt, which, when it is acted upon by yeast, produces the malted beverages, beer and ale. Maltose by invertin of yeast is changed into glucose.

Amyloses, or Polysaccharides.—Under the influence of dilute mineral acids the amyloses are changed by boiling or are transformed into glucose. Starch presents a polarizing cross: black cross upon a white ground or a white cross upon a black ground. Starch does not reduce copper solution nor is it fermentable by yeast. When iodine is added to starch it gives a blue color.

Glycogen, or animal starch, does not reduce copper salts nor is it fermentable by yeast. During the hydrolysis of starch dextrin is formed as an intermediate product. Dextrins colored red by iodine are called erythrodextrins; those not colored by iodine are called achroödextrins.

2. FATS.

Fats form a more or less variable proportion of the animal economy. They come to us principally in the form of animal food. but to some extent in vegetable food, also, especially in seeds, nuts. fruit, and roots.

The fats contain in their substances a fatty principle having acid properties—a sort of fatty acid. When acted upon by alkalies and ferments, this acid becomes separated and a sweet principle known as glycerin makes its appearance. Thus fats may be said to be compounds of fatty acids with glycerin. It would seem, however, that the glycerin had not pre-existed in the fats, as the united weight of the glycerin and the fatty acid produced exceeds that of the fat originally employed.

In bone-marrow, adipose tissue, and milk, the fats are very prominent components. The adipose tissue consists of nucleated vesicles filled with fatty matter. The vesicles are closely packed together and are surrounded by a network of blood-vessels which draw out from this source a supply for nutrition. This fatty tissue is found between the muscles, bones, vessels, etc., and, by its accumulation under the skin, gives to the surface of the body its full and regular outline.

By reason of its bad conducting power, it helps to keep the various structures of the body warm by a coating of it lying under the skin. This fact is best illustrated in warm-blooded aquatic animals, such as the seal, porpoise, or whale.

The normal fats found in the body and used for food are divided into three compounds: *stearin, palmitin,* and *olein.*

Stearin is the most solid of the three. It is typically illustrated in mutton suet, and is the element which makes this fat so hard and firm, and characterizes it at once. Its melting-point is 145° F., so that at ordinary temperatures it is solid.

Palmitin occupies a position midway between stearin and olein as regards consistency. It is the principal constituent of most animal fats, and occurs largely in vegetable fats also.

Olein is always found in a fluid state unless the temperature be very low. When the olein ingredients predominate in a body it is then in a liquid state, as in the case of the oils. Olein is found in both animal and vegetable fats, but the vegetable fats are richer in it than the animal. The oils used in food—olive-oil, oil of sweet almonds, etc.—are derived from the vegetable kingdom.

Human fat contains about 75 per cent. of olein plus a small quantity of fatty acids in a free state. All are soluble in hot alcohol, ether, and chloroform, but insoluble in water.

Saponification.

When fat is boiled with alcoholic soda or potash, the particles of fat are broken up into a small quantity of glycerin and a large quantity of fatty acid. The fatty acid unites with the soda or potash, forming, as a result, soap. This process of soap-forming is known as saponification.

Emulsification.

If oil and water are well shaken together the fatty particles do not form a part of the water, but are held in suspension and come to the surface in the form of small globules. A mixture of an oil, a soap, and water is spoken of as an emulsion. No emulsion is permanent, for even in milk, the most perfect of emulsions, the fatty particles in the form of cream rise to the surface in a few hours.

Emulsification is a physical or mechanical rather than a chemical change. Both soaps and emulsions are continually being formed in the body during the digestion of fats.

3. PROTEIDS, OR PROTEINS.

The principal constituents forming the muscular, nervous, and glandular tissues, as well as the serum, blood, and lymph, are proteids. In normal urine there are found no proteids, or, if any, only traces. In a great measure the various phenomena of life are present and due to the protoplasm in the cells. On analyzing protoplasm chemically its substance is, of course, killed by the reagents used, but proteids invariably result in the process. Whether the proteids exist as such in the protoplasm, or occur only after the death of the protoplasm, has not been fully established, but they are believed to be the constituents of it. However, none of the phenomena of life occur without their presence.

Proteids are very complex, comprising compounds of carbon, hydrogen, nitrogen, oxygen, and sulphur. They may be either solid or liquid, as they are found in the different tissues of the body. The different classes of proteids present both physical and chemical peculiarities, although all have certain common reactions. Some are soluble, others are insoluble, in water, while nearly all are soluble in ether and alcohol. Strong acids and alkalies are also capable of dissolving the proteids, but in the process of dissolution decomposition almost invariably occurs.

The supply of proteids in our bodies is obtained from the vegetable kingdom, being taken in as vegetables directly, or indirectly in the form of meat which is derived from animals that live on vegetables. Thus the proteids are built up from the simpler inorganic compounds taken from the soil and air and elaborated in plant-structure.

The chemical composition of the proteids is variable, depending upon the products analyzed by the different investigators, as the purity of the substances cannot be definitely determined. From investigations we have the following average percentages: O, 21.50 to 23.50; H, 6.5 to 7.3; N, 15.0 to 17.6; C, 50.6 to 54.5; S, 0.3 to 2.2.

The nitrogen and sulphur are each contained in the molecule in two forms, the one loosely combined, the other firmly combined. The basis of construction of all proteids is, according to Kossel, a body called protamin ($C_{30}H_{57}N_{17}O_6$), which on hydrolysis gives three basic substances each containing six carbon atoms, hence called hexone bases, lysin, histidin, and arginin. Protamin has been found loosely combined with nucleic acid in the spermatozoa of fishes. In the proteid molecule it is firmly combined with the amido acids, like leucin, glycin, and usually with the aromatic bodies, like tyrosin, etc., and inorganic elements, like sulphur and phosphorus.[1]

The proteids of different animals seem, to rough chemical tests, to be the same; but the precipitin test shows a difference between them. The casein of cow's milk is not exactly similar to that of woman's milk.

More is required than a mere equivalent of nitrogen to cover the loss of nitrogen from the body.

Polypeptids.

In the first ten years of the nineteenth century Chevreul laid bare the nature of fats in the process of the making of soaps, and in 1854 Berthelot, by means of glycerin and fat acids, constructed synthetically a fat. In 1890 grape sugar was synthetically produced by Fischer. As regards proteins, Miescher, in 1874, detected in the semen of the salmon the protamins. In the last few years Fischer has been able to unite the amido-acids. He has made a body containing 14 amido-acids. It is called l-leucin-triglycyl-l.-leucyl-oktaglycyl-glycin. Organic synthesis is not yet eighty years old, for Woehler first produced urea in 1828. Fischer hopes shortly to produce peptones from the polypeptids.

Proteids consist of long chains of relatively simple molecules, which by hydrolysis into amino-acids are the keystones of the proteid compound.

When proteids are split up by either ferments or chemical agents, the general order of the products is the same. The first action is to produce proteids which have smaller molecules than the original native albumin. These products are denominated albumoses. The next stage is the formation of still smaller molecules of peptone, and finally the peptone breaks up into smaller crystalline materials of known composition, which do not give typical proteid reactions. The above chemical reactions are hydrolyses.

These bodies can be arranged into groups:—

(1) Monoamino acids, such as glycin or glycocoll, leucin, aspartic acid, glutaminic acid, etc.

(2) Diamino acids, as lysin, arginin, valeric acid, containing a

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[1] Beddard, "Practical Physiology."

ure. radical like creatin and histidin. The introduction of a second amino or NH_2 group confers basic properties upon the acid; hence the name hexone bases—hexone because all contain six atoms of carbon.

(3) Aromatic amino-acids, such as phenylalanin, tyrosin, and tryptophan, the mother substance of indol and skatol.

(4) Pyrimidin bases, such as thymin (cytosin) and pyrrolidin derivatives.

(5) The sulphur-containing substance, cystin.

(6) Ammonia.

Some of the amino-acids belong to the aliphatic series, others to the aromatic and some to the heterocyclic compounds. Nearly all the amino-acids have been made synthetically. All of the amino-acids from proteid, except glycocoll, contain one or more asymmetrical carbon atoms, and hence are optically active. Thus, the leucin of protein is l-leucin; the alanine rotates the ray to the right, hence it is d-alanine. The same amino-acids are present in nearly all vegetable and animal proteids, though certain exceptions exist. Thus, gliadin from wheat flour contains no lysin, and gelatin has no tyrosin and tryptophan.

Glycocoll is not found in egg albumin, casein or oxyhæmoglobin, whilst it makes nearly one-third the weight of silk fibroin. Glutaminic acid is not found in silk fiber, whilst in gliadin there is about 36 per cent., and arginin varies from 2 per cent. in zein to 84 per cent. in salmin.

The amido-acids have been shown by Fischer to possess the property of combining with one another to make complex molecules containing two, three, or more groups of amido-acids. Thus, two molecules of amido-acid (glycocoll) may be made to unite to form a compound, glycylglycin, which Fischer calls a peptid. When formed from the union of two amido-acids, they are called dipeptids; from three, tripeptids; from more complicated compounds of this kind, the polypeptids, which have a reaction similar to that of proteids. The polypeptids occupy in proteolysis a stage between the peptones and the final simpler amido-acids, and can be found in peptic and tryptic digestion of albumin.

We may write the formulæ for the three typical amino-acids as follows:—

Glycin—HNH, CH_2, COOH (amino-acetic acid).

Alanin—HNH, C_2H_4, COOH (amino-propionic acid).

Leucin—HNH, C_5H_{10}, COOH (amino-caproic acid).

In each, the first and last groups are the same, the middle group varies and may be represented by R. The general formula of the mono-amino acids is, therefore: HNH, R, COOH.

If now we link these two together, we get HNH, R, CO, $\boxed{\text{OH H}}$ NH, R, COOH. What happens is that the hydroxyl (OH) of the carboxyl (COOH) group of one acid unites with one atom of the hydrogen in the next amino (HNH) group, and water is thus formed, as shown in the oblong, and the rest of the chain closes up and the water is eliminated. In this way we get a dipeptid. The names glycyl, alanyl, leucyl, etc., are given by Fischer to the NH_2, R, CO groups which replace the hydrogen atom of the next NH_2 group.[1]

Thus: glycyl-glycin, glycyl-leucin, leucyl-alanin, alanyl-leucin, and numerous other combinations and permutations are obtained.

If the same operation is repeated, we obtain tripeptids (leucyl-glycyl-alanin, alanyl-leucyl-tyrosin, etc.); then we have the tetrapeptids and so on; and in the end, by coupling the chains sufficiently often and in appropriate order, Fischer has already obtained substances which give the reaction of a peptone.

Hence we may consider proteids as essentially polypeptid compounds of greater or less complexity; that is, they are acid-amids formed by the union of a number of amido-acid compounds. Many of the polypeptids have been produced synthetically, and these facts lead to the hope that the actual synthesis of the proteid molecule may be finally accomplished.

About 100 polypeptids have been synthetically prepared. The variety of forms possible is almost infinite when one considers the variety of combinations which may take place. The peptids and polypeptids synthetically prepared are not split into their component amido-acids by pepsin, but trypsin splits some of them, especially those formed from the optically active amino-acids which occur in nature.

The inquiry into polypeptids of a definite construction has led to the isolation of such compounds directly from the proteins, and will aid us in understanding the more complex substances, as proteoses and peptones. They consist of mixtures of complex polypeptids, but at present our methods are not perfect enough for separating polypeptids from one another and from amino-acids.

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[1] British Medical Journal.

Classification of Proteids or Proteins.

For the sake of convenience and study the proteids have been divided into various groups and classes by different authorities. They are almost universally divided into the two main groups of *animal* and *vegetable* origin. The amount of proteid matter in plants, particularly the full-grown ones, is less than in animals. It is found dissolved in their juices, in the protoplasm, or deposited in the form of grains called *aleuron* granules. Vegetable proteids are divisible into the same classes as the animal, but, since human physiology deals with animal proteids, the vegetables are disregarded.

A convenient classification is: (1) *native albumins,* (2) *derived albumins,* or *albuminates,* (3) *compound proteids,* (4) *globulins,* (5) *peptones,* (6) *albuminoids,* (7) *histons,* and (8) *protamins.*

1. Native Albumins.

The proteids of this class are those that are found in an unaltered, natural state or condition in the solids of the body. They are soluble in water and are not precipitated by the dilute acids. The two main forms are *egg-albumin* and *serum-albumin.* The *egg-albumin* occurs in the part of the egg known as the white. The *serum-albumin* is found not only in the blood-serum, but also in the lymph as it is found in its proper lymphatic channels and diffused throughout the tissues, in the chyle, milk, and transudations.

2. Derived Albumins, or Albuminates, or Meta-proteins.

To this class belong two divisions: *acid-albumin* and *alkali-albumin.*

The derived albumins are formed from the native albumins by the action of weak alkalies or acids. Thus, when a native albumin, such as serum-albumin, is treated for a while with dilute hydrochloric acid its properties become entirely changed. The solution is no longer able to be coagulated by heat, and when the solution is carefully neutralized the whole of the proteid is thrown down as a precipitate. The substance into which the native albumin was changed by the action of an acid is called an *acid-albumin,* or syntonin. This acid-albumin is insoluble in distilled water and neutral saline solutions, but readily soluble in dilute acids and alkalies. This is the process through which albumins pass when undergoing gastric digestion and when acted upon by the HCl of the gastric juice.

If serum-albumin, egg-albumin, or washed muscle is acted on by an alkali, instead of an acid, the proteid undergoes changes similar to those produced by the acid, except that the product formed is an *alkali-albumin* instead of an acid one.

3. Compound Proteids, Conjugated Protein, or Proteides of Germans.

These are native proteids with another organic substance, in contrast to albuminates, which are compounds of native proteids with inorganic substances. The compound proteins include (1) glucoproteins, like mucin, consisting of a proteid combined with a carbohydrate group; (2) nucleoproteins are built up of albumins, nucleic acid, and always contain iron. They exist in the cell-nucleus; (3) phosphoproteins, like casein of milk and vitellin of yelk of eggs; (4) chromoproteins, like hæmoglobin.

Tests for Proteids.—(A) COLOR TESTS.—(1) The biuret test of Rose and Wiedemann,—when a solution of albumin is made strongly alkaline with caustic potash, and a solution of copper sulphate is added drop by drop, then a pink-violet color is produced.

(2) The xanthoproteic test of Fourcroy and Vauquelin. Add nitric acid, and a white precipitate ensues, which, on being boiled, turns yellow; on cooling, add ammonia; the yellow-colored precipitate becomes orange. This reaction depends upon the presence of the benzol ring in the proteid molecule (phenylalanin, tyrosin, indol).

(3) Millon's reagent. This reagent is a solution of mercuric nitrate in water containing free nitrous acid. On adding it to a solution of albumin, a whitish precipitate ensues, which becomes a brick-red on boiling. This reaction indicates the presence of oxyphenol group (tyrosin).

(B) PRECIPITATION OF PROTEIDS BY NEUTRAL SALTS.—(1) Saturation with ammonium sulphate precipitates all proteids except peptones.

(C) PRECIPITATION OF PROTEIDS BY ACIDS.—(1) Add a drop or two of strong nitric acid, a white precipitate ensues.

4. Globulins.

The globulins are quite abundant. The globulins differ from the albumins in that they are not soluble in distilled water. There must be present an appreciable amount of sodium chloride or magnesium sulphate.

Globulins are insoluble in saturated solution of all the neutral salts. They are also insoluble in a half-saturated solution of ammonium sulphate. They are coagulated by heat.

The different members of this group are: *serum-globulin (paraglobulin),* and *fibrinogen* in blood, *myosinogen* in muscle, etc.

Paraglobulin is a precipitate that can be formed from blood-serum by diluting it tenfold with water, and passing through it a current of carbon anhydride. A flocculent, and finally a granular, precipitate results, which is the paraglobulin.

The coagulated proteids are fibrin, myosin, and casein. The coagulation is produced by ferments.

Fibrinogen is present in the blood, chyle, serous fluids, and transudations.

Myosinogen is the principal proteid found in muscle.

5. Peptones.

In the body *peptones* are the final results of the action of the gastric and pancreatic juices upon the native proteids, and, as peptones, are ready for absorption by the cells. Although formed in large quantities in the stomach and intestine, they are absorbed as soon as formed, since none are left in these organs. Peptones can, however, be produced outside the body by the action of dilute acids at medium temperatures.

The peptones are soluble in water, not coagulated by the presence of heat, cannot be precipitated by the usual proteid precipitants, and diffuse very readily through membranous tissues.

Siegfried has recently isolated peptones of a basic character by hydrolysis of albumins with about 12 per cent. of hydrochloric acid. He calls these bodies kyrines.

Intermediate products between the native proteids and peptones are the *proteoses.* True peptones are not found in the circulating juices of plants, but the product found is very likely proteose.

The proteoses are only slightly diffusible, they are not coagulated by heat, but can be precipitated. A characteristic feature of their precipitates is that they can be dissolved by heating, but reappear when the solution cools.

6. Nitrogenous Bodies Allied to Proteids, or Albuminoids, or Scleroproteins.

Besides the proteids there are other nitrogenous, noncrystalline bodies that are allied to the former, having many general points in common.

Gelatin is the substance produced by heating in dilute acetic acid for several days, the collagen of connective-tissue fibers. It possesses the property of setting into a jelly when its concentration is greater than 1 per cent. When digested it is converted into a peptone, and, although readily absorbed, is not able to take the place of a true proteid, since it cannot build up nitrogenous tissue, being valuable only as a means of storing up energy.

Keratin is the horny material forming the outer layer of the epidermis, hair, wool, nails, hoofs, etc.

Elastin of elastic tissue belongs to this group.

7. Histones.

To the histones belong globin, the proteid which is separated from hæmaglobin by decomposing acids and alkalies.

8. Protamins.

The protamins are salmin, clupein, scombrin, sturin, etc.

ALIMENTARY SUBSTANCES.

We have learned that the body is composed of the chemical constituents or proximate principles, carbohydrates, fats, and proteids comprising the organic group, and water and salts the inorganic class. In order that the nutrition of the body may proceed normally, it is very apparent that those principles must be supplied in the food, in the proper proportions and quantities. So, a proper diet for man is one containing the proximate principles in their proper proportions, the value of it depending mainly on the amount of carbon and nitrogen present.

The elements, as elements, are not valuable; it is only when they are in combination that they serve their proper ends as foods. For the elements, to constitute an organic product, must be united previously by some living organism. It is not often that the alimentary substances are used by us as Nature furnishes them, even though they contain the proper ingredients. One requisite is that they should be presented in a digestible form. Water, heat, and condiments are the three agents used to make food more palatable and digestible. Water helps to soften the insoluble substances, and to dissolve the principal substances. Heat modifies the foods still more, so that they acquire different characters. Condiments give physical satisfaction and enjoyment, and, at the same time, they please the taste.

A diet, to be sufficient, must be adapted to the particular individual's need, keeping in mind, also, the climate, age of person, and the amount of work done by him.

We make changes of clothing to suit the weather conditions in order that the body may not suffer in regard to the surrounding temperature, and our diet should be regulated with the same ends in view. In cold weather we eat more, to furnish an extra amount of heat; in warm weather we eat less than usual. A growing youth's body must not only repair the daily waste, but also assist in constructive metamorphosis, or growth, so that he requires relatively more food *per diem* than the adult. Because of the waste attending action, the workingman requires more than the ordinary supply of food.

There are some single foods which contain all the necessary proximate principles in proper proportions, but they are the exceptions, rather than the rule. Thus milk and eggs are classed as perfect foods. It is usually necessary for a proper diet to contain a variety of substances in this list.

For a man doing a moderate amount of work, it has been computed that it is necessary that the daily diet should contain the following amounts:—

Proteid	125 grams.
Fat	50 grams.
Carbohydrates	500 grams.

Alimentary substances comprise products of both animal and vegetable kingdoms. The principal ones are animal substances, with cereals, potatoes, drinks, condiments, cocoa, coffee, tea, etc.

The *animal substances,* or foods, comprise: (1) meat, (2) eggs, and (3) milk, with its derivatives—cream, butter, and cheese.

The parts of animals used for food are the various portions of their muscular system. They comprise the general term meat. Animal food, being identical with the body structures, requires nothing to be added or subtracted to make it fit to give proper nourishment.

MEAT.

The more compact the fiber, the less digestible the meat. Hence ham is much less digestible than other meats. The more fat that is combined intimately with the fibers, so much less is the digestibility of the meat, because the fat melts and coats the fibers of the meat with a layer of oil which prevents the ferment from acting upon it.

Meat is noted for the large quantity of nitrogenous matter which it contains, containing four times the amount of proteid compared with the same weight of milk. The proteid in meat is myosin, the main constituent.

Beef-tea is a solution of gelatin, salts, extracted matters, a little albumin, together with some fat. The value of beef-tea as an alimentary substance has been much disputed, some claiming great results from it, others none. However, one thing is certain; it possesses a stimulant and restorative value, though it must not be depended upon as a food and administered as such.

LIEBIG'S BEEF TEA.—It contains novain, oblitin, ignotin, and neosin. Oblitin increases the tonus and peristaltic movements of the intestine. It also increases the salivary secretion and lowers arterial tension. Novain has a similar action to oblitin. Neosin lowers the arterial tension. Neosin is also obtained from fresh muscle, and is not due to putrefactive changes in beef-tea.

The process of cooking meat loosens up the various fasciæ and enveloping membranes, thereby separating the fibers; at the same time parasitic growths are killed. Thus the digestive juices are given more ample opportunity for acting upon all parts of the foods, even penetrating into the innermost parts.

EGGS.

The white of an egg is a faint-yellowish, albuminous fluid inclosed in a framework of thin membranes, and this fluid itself is very liquid, but seems viscid, because the membranes are entangled. Ovalbumin, or the egg-albumin of the egg-white, is the chief constituent. The mineral bodies in the white of the egg are potash, soda, lime, magnesia, iron, chlorine, phosphoric acid, and sulphuric acid.

The principal part of the yelk is an orange-yellow, alkaline emulsion of a mild taste. The yelk contains vitellin as its principal constituent. Besides vitellin, the yelk contains alkali albuminate and albumin. The yelk also contains a phosphorized fat (lecithin) with cholesterin, fats, and a small quantity of sugar and of mineral bodies, chiefly lime and phosphoric acid. Iron exists in the yelk in an organic combination.

As the egg is so easily digested it is prized highly as a food. However, the more that an egg is boiled, the more insoluble do the proteids become and so are more indigestible.

In cases where eggs are difficult of digestion the white of egg may be given. In some persons the yelks of eggs cause headache and drowsiness. The caloric value of two eggs is about twenty calories; about equal to the heat-value of a tumbler of milk.

MILK.

Like eggs, milk contains all the elements necessary for the maintenance of life, and hence it is regarded as a type of alimentary substances and classed as a perfect food. It serves very well as an infant-food.

The quantitative composition of cow's milk and human milk is as follows, according to Bunge:—

	Proteid.	Fat.	Carbo-hydrate.	Salt.
Cows' milk	3.5	3.7	4.9	0.7
Human milk	1.7	3.4	6.2	0.23

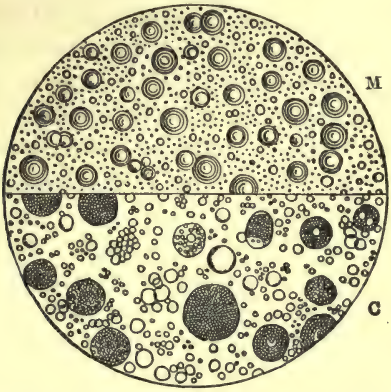

Fig. 6.—Specimens of Milk, viewed through the Microscope. (Landois.)

M, Milk. *C*, Colostrum.

The amount of fat and carbohydrate is nearly the same in both, there being, however, twice as much proteid and nearly three times as much salt in cows' milk as in human milk. To bring cows' milk to the same condition as human milk, it is necessary to dilute with an equal amount of water, and, at the same time, to add some cream and sugar.

Milk is a watery solution of various proteids, a carbohydrate and salt, containing in suspension emulsified fat. Cows' milk is an opalescent solution, with a characteristic taste and an amphoteric reaction. The specific gravity varies between 1028 and 1034. Microscopically, it consists, like blood, of plasma and corpuscles, or globules, of fat. Boiling does not coagulate fresh milk, but forms a skin on its surface, which is chiefly composed of caseinogen inmeshing some fat-particles. This film is formed by the drying of proteid at the surface of the milk. The chief proteid of milk is a phospho-proteid called caseinogen, which can be precipitated by adding to the diluted milk a weak acid or by saturating it with a neutral salt. The chief peculiarity of caseinogen is its coagulating power when treated with a ferment, rennin, in the presence of lime salts. The coagulation of milk depends upon the change of a soluble proteid, caseinogen, into an insoluble body, casein, by means of the enzyme, rennin, and the presence of lime salts is necessary. It is probable that the rennin first splits the caseinogen into two bodies, the more important being soluble casein, which then combines with the calcium salts to form a caseinate of calcium, while the other passes into solution in the whey as whey proteid, or lactoserum proteose.

The casein thus generated inmeshes the fat-granules and forms milk-curd. This curd, like the blood-clot, shrinks after a few hours and an opalescent fluid, or serum, called *whey,* is expressed.

This whey contains, besides the whey-proteid, or lactoserum proteose, traces of other proteids and also lactose and milk salts. The casein of cows' milk forms large masses on coagulation, while women's milk forms very fine flakes.

The lactose, or sugar of milk, does not readily ferment with yeast, but it is capable of undergoing a special fermentation, by which it is changed by the lactic acid bacillus into lactic acid, and this lactic acid is further split up into butyric acid. These two acids, lactic and butyric, precipitate the caseinogen and produce the curd in sour milk; but this curd is quite a different body from that produced by rennin, for it can be dissolved by a weak alkali, and then the rennin will clot it. Potassium oxalate, which precipitates the calcium in the milk, prevents the clotting of the milk. The other proteids in milk, besides caseinogen, are lactalbumin and lactoglobulin.

Kumiss is mare's milk fermented. It contains 10 per cent. of solids, 3 per cent. of alcohol, 2 per cent. of fat, 2 per cent. of sugar, 1 per cent. of lactic acid, 1 to 2 per cent. of casein, and 1 volume per cent. of carbonic acid.

Kephir is cows' milk fermented by kephir grains.

Matzoon is prepared by adding to milk a ferment consisting of some form of yeast and the lactic acid bacilli. It, however, contains very much less alcohol and carbonic acid than kumiss. Plasmon is prepared by precipitating casein from fresh milk. Then it is dissolved in sodium bicarbonate in the presence of free carbon dioxide, which prevents the alkali from decomposing the casein. It is then dried, and is a yellowish-white body. It contains 2 per cent. of fat and milk-sugar and 7 per cent. of salts. It is used as a substitute for milk when a large amount of water is not desirable.

The fats of milk are olein, palmitin, stearin, caproin, and butyrin. The milk of women contains twice as much olein as palmitin and stearin, but these bodies are about the same in quantity in cows' milk. In cows' milk two-fifths is olein, one-third is palmitin, one-sixth stearin and butyrin, and caproin one-fourteenth of the total fat.

Buttermilk contains about 10 per cent. of solids, including casein; lactose; and about 1 per cent. of fats.

Butter is formed in churning by making the fat-particles adhere to each other, forming a yellow, fatty mass.

The salts of milk average 0.6 per cent. and they consist chiefly of phosphate of lime with calcium chloride, magnesium phosphate, and traces of iron.

Milk also contains about 7.6 per cent. of carbonic acid and traces of oxygen and nitrogen.

The quantity of milk daily secreted by a woman is about one quart.

The quantity of milk changes during lactation, which lasts in the woman about ten months. In the case of the woman, the percentage of casein and fat increases to the end of the second month, but sugar lessens even in the first month. During the fifth to the seventh month there is a diminution of fat, and between the ninth and tenth months a decrease of casein. In the first five months the salts increase; after that they diminish.

Colostrum is the milk secreted for a few days after parturition, and it has peculiar characteristics. It contains large corpuscles called colostrum-corpuscles, which are large cells full of colorless, fatty particles.

A poisonous principle is sometimes generated in milk by microbes. It is called tyrotoxicon.

VEGETABLE FOODS.

Vegetable substances differ very much from animal bodies in their physical appearances, and, in some respects, also chemically. The vegetable matters are capable of being transformed into the various animal components and thereby nourish the animal body, since they contain all the elements, or proximate principles, that are necessary for the maintenance of life. They need a more complex apparatus for their transformation, and, as a consequence, the digestive organs of the herbivora are better developed and more complex than those of the carnivora.

The *cereals* have the same general composition, all containing the same proximate principles, but not all possess the same relative amounts, because of which some are more valuable as food than others. The most important of the cereals is *wheat.*

Wheat, as a source of food, occupies a very important place and is one of the most widely cultivated of the cereals. The wheat-grains by grinding have their cellulose coats burst, and the resulting powder is called flour. This contains, on an average, 70 per cent. of carbohydrates, 8 per cent. of proteid, and 1 per cent. of fat. The coverings of the grain still contain some albumin and starch and thus form bran, a substance used for feeding the herbivora. Bread is made by a mixture of wheat-flour and water, forming dough. The body which, on the addition of water, becomes viscid is called gluten, and is a tough, sticky mass. This is made more porous by carbonic acid, which is generated in the dough by the action of the yeast-plant on sugar. The sugar is produced by the diastase in the flour, which hydrates the starch into sugar. Baking kills the yeast-action and makes the vesicles filled with carbonic acid expand, so the dough is filled with little cavities. The crust of bread is formed by the heat coagulating the gluten, and at the same time the heat transforms the starch into dextrin and soluble starch. The glazing of the crust is due to dextrin. The color of the crust and its taste are due to a caramel generated by the action of heat on the sugar produced by the diastase.

ACCESSORY FOODS.

In addition to the ordinary foods there is a series of articles which are not necessary to the maintenance of life, but which are frequently used. They are: alcohol, tea, coffee, and cocoa. Of these accessory foods, alcohol is the predominant one and is used in a variety of drinks.

Alcohol.—Beer contains from 3 to 5 per cent. of alcohol. It also has from 5 to 7 per cent. of extractives, which consist mainly of dextrin and maltose, with albuminose, which give it nutrient properties. Each ounce usually holds about two cubic inches of carbon dioxide. It is an infusion of malt fermented, to which a bitter principle found in hops is added. It is frequently adulterated with salicylic acid and benzoic acid to preserve it. In excess it gives rise to rheumatism, gout, and bilious attacks, due to diminished excretion of waste-materials from the economy. Wines contain from 6 to 25 per cent. of alcohol. Port holds 10 per cent. and sherry 16 to 25 per cent. of alcohol. Besides, the aroma is due to ethers. Champagnes contain in addition, 10 per cent. of sugar, which upsets the stomach. Wines also have free acids, especially tartaric, which also disagree with certain stomachs.

Spirits contain about 50 per cent. of alcohol. Alcohol is a nutrient and heat-generator. One gram of alcohol produces more heat than one gram of proteid or carbohydrate. Ordinarily the system can oxidize daily about one and one-half ounces of alcohol. When alcohol is oxidized it spares the fats and carbohydrates and probably the proteids. It is well known that the continuous drinking of alcohol makes a person fat. The persistent use of alcohol also increases the dangers of infection from infectious diseases. In fevers its use prevents the loss of fat and stimulates the secretion of gastric juice. It dilates the capillaries of the skin either by a local or central action, favoring heat-dissipation. Its habitual use gives rise to chronic gastritis and cirrhosis of the liver. The odor of spirits in the breath is due to fusel-oil. Alcohol in the blood is changed into carbonic acid and water.

Coffee.—Each cup of coffee contains about two grains of caffeine. Coffee also contains a volatile substance called coffeon, which resembles an oil. The exhilaration after the drinking of coffee and the increased peristalsis are due to the coffeon.

Tea.—Tea contains caffeine and theophylline and about 7 per cent. of tannin. Tea induces constipation and chronic gastritis when used in excess. Neither tea nor coffee diminishes metabolic changes.

Cocoa.—This body is a nutrient because it contains fat (50 per cent.) and an albuminous substance. It contains theobromine. Caffeine and theobromine belong to the purin group.

CHAPTER III.

DIGESTION.

Anatomy and Structure of the Mouth, Pharynx, and Œsophagus, together with the Digestive Processes Occurring in Them.

Digestion has for its aim the separating of the principles of growth and repair from the aliments and the fitting of them for absorption into the circulation. The process is both mechanical and chemical, accomplished mainly through the action of certain soluble ferments called digestive enzymes.

Some form of digestion is found to take place in all animal organisms no matter how low we proceed in the zoölogical scale. It is essential to every one of them that they be able to take from their environments those elements that are necessary to maintain their economy and to give off those substances termed waste-products that are no longer fit for use, for only by this exchange of the elements outside of their own organisms are they able to live, grow, and produce others of their kind.

In the higher grades of animal life, as the articulata and vertebrata, the number of organs concerned in digestion is increased, and, of course, in direct ratio the various stages and acts in the whole process are multiplied. In their bodies it is a long tube, in some parts much folded on itself; in and along the outside of this tube there are numerous glands which empty their products, called secretions, into the long tube; at the beginning of which there is an apparatus for crushing and grinding the solid parts of the food. Intimately connected with this apparatus is the system of blood- and chyle- vessels for absorbing the digested products, thus allowing them to circulate through the entire body and come into contact with every part of the organism.

In the vertebrata there are modifications and forms of development dependent upon the class, and even in mammalia there are differences, as the animal may be insectivorous, carnivorous, herbivorous, or omnivorous.

Man, the highest of the mammalia, is the real and intimate study upon which all our physiological researches bear. He is omnivorous, and naturally we expect to find his digestive apparatus suited to disintegrating and dissolving *all* kinds of food.

In him the digestive apparatus consists of a long tube, called the alimentary canal, about thirty feet in length, with its accessories, the teeth and the various glands which empty their products into the tube by means of little ducts.

The *alimentary canal* is the long tube beginning with the mouth and ending with the anus, composed of muscle and mucous membrane, the latter lining it throughout its entire length and giving to the interior of the canal its characteristic smoothness and redness. In this lining membrane, as also in the submucosa, are located some of the glands whose secretions aid digestion.

The alimentary canal in its extent of about thirty feet has received various names for its several parts. They are: *mouth, pharynx, œsophagus, stomach, small* and *large intestines.*

The *mouth* is an oval box situated at the commencement of the canal, in which, by the action of the jaws with their two rows of teeth, the hard parts of the food are *masticated.* While the food is being masticated, it is at the same time being mixed with a watery fluid, the *saliva,* the secretion of the *salivary glands;* this mixing of food and saliva has been termed *insalivation.*

In the *pharynx* and *œsophagus* occurs the act of *deglutition,* or swallowing of the masticated mouthful, in the form of a large, moist bolus. It is by the contraction of the muscles in these parts, that the food is quickly passed on to the stomach. The course of the tube, beginning with the mouth and ending at the opening of the stomach, is comparatively straight, and measures about fifteen or eighteen inches in length. This part of the tube is found in the head, neck, and thorax, ending just below the transverse muscular wall of the trunk, the diaphragm.

The *stomach* is the muscular pouch in which occur some of the chemical changes of the food, converting it into a grayish-brown souplike mass. From thence it passes into the *small intestine,* where the nutrient materials are separated from the waste-residue; the latter is passed on into the *large intestine* to be later expelled from the body.

The *stomach* and the *large* and *small intestines* are located in the abdomen and pelvis, differing from that part of the canal above the diaphragm in that the intestines are much folded and convoluted in their course; so that the major portion of the entire length of the canal is contained here.

In the mucous membrane and submucosa are located microscopical glands whose ducts open directly upon the lining, interior surface. Outside the canal, their secretions emptying into the canal by small ducts, are the larger glands, *salivary, liver,* and *pancreas.* The ducts of the salivary glands open into the mouth; the common duct of the liver and pancreas opens into the first fold of the small intestine, the *duodenum.*

Although digestion in its entirety, as it occurs in the alimentary canal. is in its nature very complex, yet there are *three* natural divisions of the whole process based upon the changes as they occur (1) in the *mouth* (including the pharynx and œsophagus), (2) in the *stomach,* and (3) in the *intestines.*

It is the intention to consider the changes and alterations of the foodstuffs, whether mechanical or chemical, in each, together with the anatomy of the parts of each division and the structure of the accessory glands, with their secretions and the functions they bear to the completion of the entire work. However, the fact must not be lost sight of that these divisions are only arbitrary and for convenience, as no real line can be drawn at the various stages, since all parts, structures, and functions work in harmony, on the plan of division of labor: having in mind one common end—the dissolving of the food so that it can become a part of the circulation.

PREHENSION.

Before the processes of digestion can begin, it is essential that the food should be brought to and placed in the mouth, the beginning of the alimentary canal, for only in some of the infusoria does digestion of the food take place outside the organism, due to the influence of ferments secreted by the organism to be nourished. The act of bringing the food to the mouth has been termed *prehension.*

Nature has admirable contrivances for this act wherever we look among the lower animals. The monkey, squirrel, rat, etc., usually make use of their anterior extremities for grasping and bringing to their mouths the food, while they sit upon their haunches. The horse makes use of his teeth and lips; indeed, his upper lip is very movable, long, and endowed with extreme sensibility. It is his means of gathering together his grain and bringing it to the incisors which cut it up, then to be passed along by the tongue to the molars for grinding. In the cow, the tongue, in the cat and dog, the teeth and jaws, are the main organs of prehension. The frog, by protruding his long, thin tongue, the surface of which is covered with a viscid mucus, catches insects as they fly.

By far the most complicated and best developed prehensile instrument in animal mechanics is that employed by *man*—the human upper limb. The extreme perfection of all its parts, and particularly of its terminal portion, the hand, makes it admirably fitted, not only for the prehension of food, but also for the execution of all the various caprices and designs of the human will. Thus it not only simply raises the food to the mouth (prehension), but also, with the human intelligence as the real potent factor, aids in the preparation of food by means of fire (cooking).

Thus we learn that the first real step in digestion is prehension: bringing the food to the mouth.

THE MOUTH.

The space included between the lips in front, the pharynx behind, and the cheeks at the side is the mouth. Above the roof of the mouth we have the palate; below, its floor, upon which rests the tongue. The cavity of the mouth, excepting the teeth, is everywhere invested with a highly vascular mucous membrane, with an investment of squamous epithelium. Conical papillæ, for the larger part minute and concealed beneath the epithelium, are found. The lips are separated by the oral fissure. They are composed of various muscles converging to and surrounding the oral fissure. The cheeks have a composition similar to the lips, and their principal muscle is the buccinator. At their back part they include the ramus of the jaw and its muscles, and usually between these and the buccinator muscle is a mass of soft, adipose tissue.

Beneath the mucous membrane of the lips and cheeks, there are a number of small, racemose glands, with ducts which open into the mouth. These glands are, in the lips, called labial and, in the cheeks, buccal. They secrete mucus.

There are two parts to the palate: a hard and a soft palate. The hard palate is deeply vaulted and lined with a smooth mucous membrane, except at its anterior part, where it is roughened by transverse ridges. The soft palate is a doubling of the mucous membrane, inclosing a fibromuscular layer, also containing racemose glands. It hangs down obliquely from the hard palate between the mouth and posterior nasal orifices. It is a freely movable partition. The uvula is an appendage like a tongue projecting from the middle of the soft palate, and consists of a pair of muscles inclosed in a pouch of mucous membrane.

Palate.—The palate has two crescentic folds of mucous membrane inclosing muscular fasciculi and diverging from the base of the uvula, on each side of the palate outward and downward, one to the side of the tongue, the other to the side of the pharynx. These folds are known as the half-arches of the palate. The one in front is known as the anterior palatine arch, the one posterior as the posterior palatine arch.

The Fauces.—The fauces is the strait, or passage, leading from the mouth to the pharynx, and corresponds with the space included between the half-arches of the palate.

The Tongue.—The tongue is composed of muscle and is covered with a mucous membrane. It is composed of two symmetrical halves joined in the middle line. By the freedom of its movements it aids in mastication and deglutition; it is also a great help in articulation, and by the papillæ on its surface forms an organ of taste. The root, or base, is the posterior part, where it is attached to the hyoid bone and inferior maxilla. The body is the great bulk of the organ. Its tip is the anterior free extremity. On the anterior two-thirds of the upper surface of the tongue, we find a mucous membrane, which adheres most intimately to the muscles beneath. Its surface is roughened by the presence of a number of little papillæ. On the surface of the tongue there are many mucous glands.

Papillæ.—The papillæ are the fungiform, filiform, and circumvallate. These are more minutely described in the section on the sense of taste.

Nerves.—The nerves of the tongue are the lingual of the fifth pair, the glosso-pharyngeal, and the hypoglossal.

THE TEETH.

In form, structure, and number, the teeth vary very considerably in different animals; this is markedly shown in the classes, *carnivora* and *herbivora.* In most animals the teeth are worn down by use and eventually decay. The exception is found in that class of animals that constantly nibble; their incisors are peculiar in that there are deposits of fresh dentine within and upon the pulp and of enamel upon the anterior surface, thus giving a continuous growth. They are the *rodentia.*

Among mammalia, and particularly in man, the teeth are developed in two sets: (1) the *first,* less numerous and smaller set, called the *temporary,* or *milk, teeth*; (2) the *second* set, larger and more numerous, called the *permanent* teeth.

The *temporary,* or *milk,* teeth are usually *20* in number, *10* in each jaw. In each jaw there are *4 incisors, 2 canines, and 4 molars.* When the milk teeth drop out they are followed by the permanent teeth.

The *permanent* teeth are 32 in number, 16 in each jaw, consisting of *4 incisors, 2 canines, 4 bicuspids,* and *6 molars.*

There are three distinct parts in a tooth: crown, root, and neck.

The crown, or body, is the protruding portion of the tooth; the portion inserted in the alveolus of the jaws is the root, or fang. The slightly constricted part enveloped by the gum, is the neck. The fang is firmly fastened to the sides of the alveolus, in which it is inserted by fibrous tissue, which is continuous with the periosteum of the jaws. When the jaws are closed the under incisors are inclosed by the upper ones, but the grinding surfaces of the molars are in contact.

Temporary Teeth.—There are 20 milk teeth, 10 in each jaw, or 5 on each side of the jaw; that is, 2 incisors, 1 canine, and 2 molars. The temporary set resembles the permanent in form and structure. The teeth are, however, fewer in number, smaller in size, and characterized by the bulging out of the crown close to the neck, making the latter very sharply defined. Lower central incisors are the first to appear. They appear about the seventh month.

The milk teeth die off and so give room for the second and more permanent set. They die partly in accordance with the rule of epithelial tissues and drop off, since all such tissues are expelled after their death; then, too, the jaws grow as the being passes from infancy to adult life, when larger and more numerous teeth must replace the smaller ones, so as not to impair the efficiency necessary to masticate quantities of food proportionate to the demands of the growing body.

Permanent Teeth.—They are 32 in number. There are 8 incisors and they form the 4 front teeth in *each* jaw, and are named incisors because they divide the food. The upper incisors are the larger. The lower molar is the first to appear in the permanent set. It appears about the sixth year.

The canine teeth are 4 in number, larger than the incisors. The upper canines are usually called the *eye teeth*, and they are longer and larger than the canine teeth in the lower jaw. In the carnivorous animals, like the dog, the canine teeth are usually large; hence the name of canine. The lower canines are popularly known by the name of stomach teeth. There are 4 premolars, or bicuspids, in each jaw. They are shorter and smaller than the canines. The bicuspids of the upper jaw are larger than those of the lower jaw. The functions of the bicuspids are to cut and grind the food. The molars are 12 in

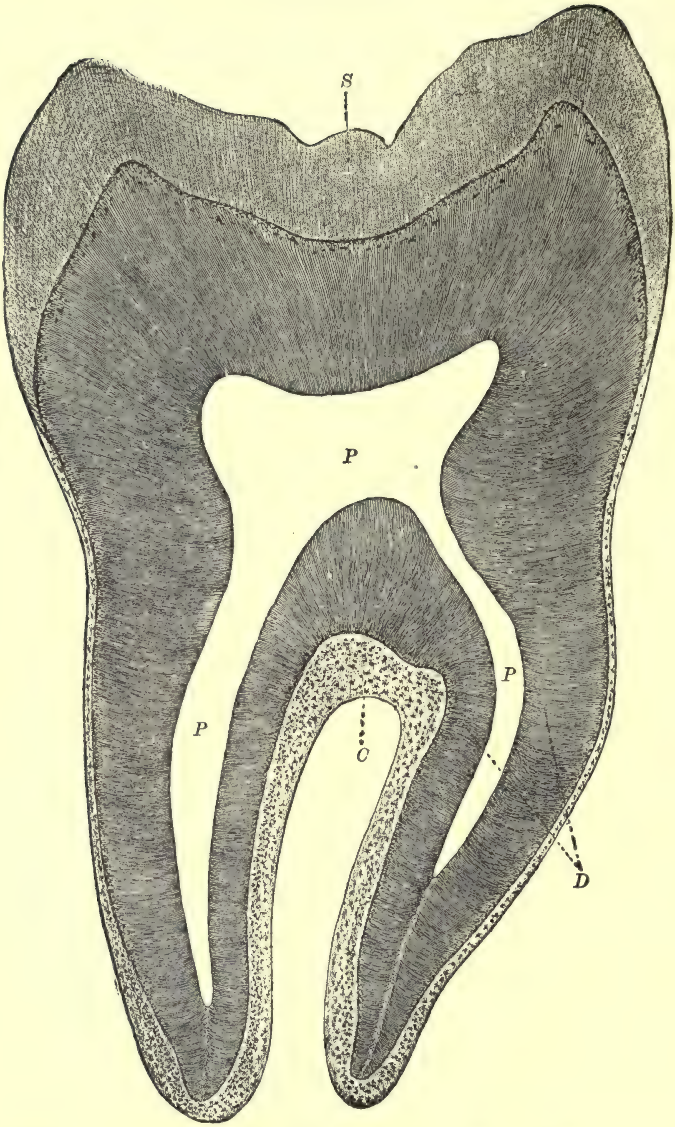

Fig. 7.—Longitudinal Section of a Molar Tooth of Man. × 8. (Sobotta.)

The figure gives a general view of the structure of the tooth. The pulp cavity is not cut its whole length in the two roots seen in the section. We recognize the three main elements of the tooth—dentine, enamel, and cementum—and their division into crown and root. On account of the low magnification, the interglobular spaces appear only as a dark zone on the surface of the dentine. *C*, Cementum. *D*, Dentine, *P*, Pulp cavity. *S*, Enamel.

number, 3 on each side above and below. Their large crown and their great width are the chief distinguishing characteristics. The upper molars have 3 conical fangs, the lower ones 2. The last molar is the wisdom tooth, so called because it appears about the twentieth year, when the individual is assumed to have acquired wisdom. The molars are intended for the grinding of food.

Structure of the Teeth.—If a tooth is split in its long axis the surface exhibits, besides the pulp-cavity, three different kinds of materials. Dentine forms the greater part of the yellowish-white substance; the capping of the crown is enamel; and the translucent, thin investment on the fang is cement, or crusta petrosa.

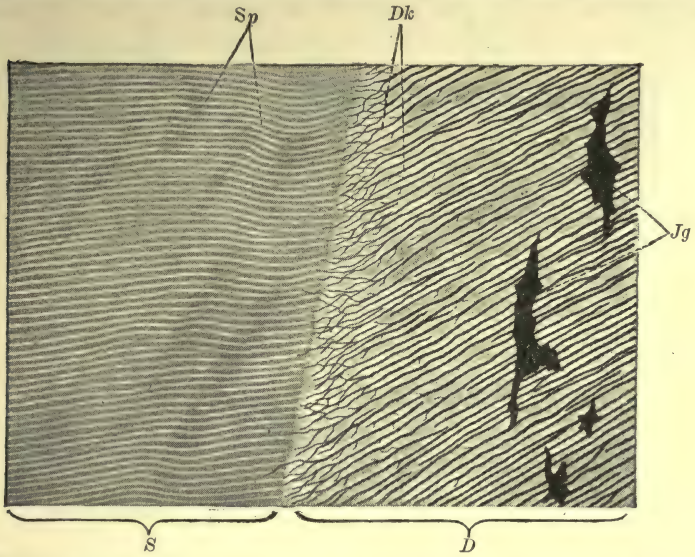

Fig. 8.—Portion of the Crown of a Longitudinal Section of a Human Premolar. × 200. (Sobotta.)

The figure shows the structure of a tooth at the border of enamel and dentine. In the region of the dentine two larger and two smaller interglobular spaces are shown. The dentinal fibers branch and fork and with their processes pass beyond the limits of the enamel. In the figure, the enamel prisms show partly wavy curves and partly alternating stripes of darker and brighter prisms (the parallel stripes of Retzius). *D*, Dentine. *Dk*, Dentinal tubules. *Jg*, Interglobular spaces. *S*, Enamel. *Sp*, Enamel prisms.

The main bulk of the tooth is composed of dentine, giving it shape and containing the pulp-cavity. It consists of about 28 parts of organic matter and 72 of earthy material. Dentine resembles bone both physically and in chemical constitution. When subjected to microscopical examination we find the dentine penetrated throughout by fine tubes called dentinal tubules. The inner ends of these tubules open into the pulp-cavity, whence they radiate in every part of the dentine toward the surface of the tooth. They have a direction generally parallel, with a wavy, undulating course. In the pathway toward the periphery they subdivide into several parallel branches which anastomose with each other. The average diameter of the tubule is $^1/_{4500}$ inch. Near the end of the tubule the arrangement is in globular spaces which communicate with each other and are known as the interglobular spaces of Purkinje, or Tomes granular sheath.

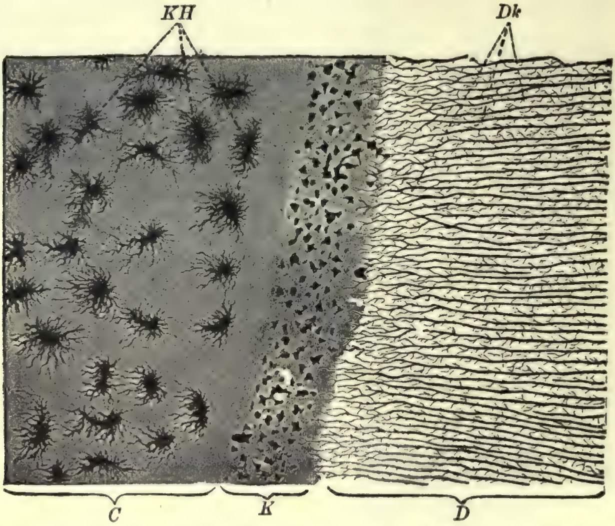

Fig. 9.—Portion of a Longitudinal Section of the Root of a Human Molar Tooth. × 200. (Sobotta.)

The figure shows the structure of the boundary between dentine and cementum. In the cementum distinct bone spaces with bone canaliculi are seen. The dentinal tubules here show especially numerous divisions and lateral branches. The granular layer shows small, irregular interglobular spaces. *C*. Cementum. *D*, Dentine. *Dk*, Dentinal tubules. *K*, Granular layer (small interglobular spaces). *KH*, Bone spaces of the cementum.

Enamel.—The hardest of all organized substances is known as enamel. It is a bluish-white material capping the crown of the tooth. It is thickest on the triturating surface of the tooth. Chemically it consists of 3 parts of organic matter and 97 of earthy matters, principally calcium phosphate. Under the microscope the enamel appears in the form of hexagonal columns about $^1/_{5000}$ inch in diameter.

The Cement, or Crusta Petrosa.—This substance covers the fang of the tooth, gradually becoming thicker toward its extremity.

It is like true bone, and contains lacunæ and canaliculi. Externally it is covered by dental periosteum. In old age the cement grows thicker and may close up the entrance to the pulp-cavity.

THE SALIVARY GLANDS.

The parotid gland is named from its position near the ear. It is the largest of the salivary glands. It extends upward as far as the zygoma, downward as far as the angle of the lower jaw, and inward between the ramus of the jaw and the mastoid process. The duct of the parotid, called Stenos, has the diameter of a crow-quill, is two inches in length, and runs across the masseter to open into the mouth opposite the second molar tooth

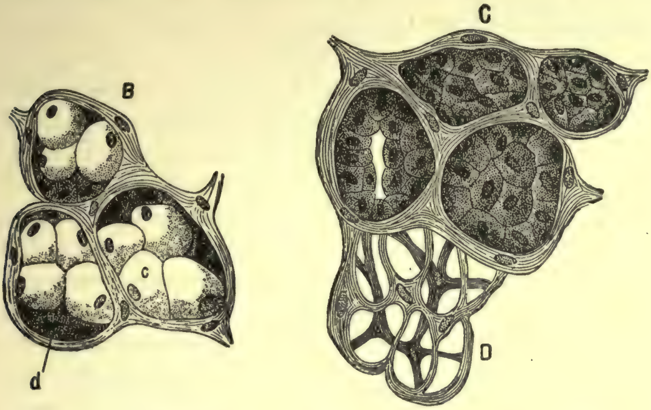

Fig. 10.—Histology of the Salivary Glands. (Landois.)

***B*, Alveoii of the rested submaxillary of the dog. *c*, The distended, glistening mucous cells. *d*, Gianuzzi's crescents. *C*, The alveoli after active secretion, showing the connective tissue of the alveoli isolated at *D*.**

The parotid has a full supply of blood-vessels, which run through it. The nerves of the parotid are the auriculo-temporal and the cervical sympathetic. In the dog and cat the parotid derives its nerve-supply from the glosso-pharyngeal through the small petrosal and the otic ganglion, the fibers finally running into a branch of the auriculo-temporal.

The submaxillary gland is separated from the parotid by a process of the deep cervical fascia. It is beneath the mylohyoid muscle, is below the curve of the digastric muscle, and on the outside is covered by the subcutaneous cervical muscle and skin. It is about one-third the size of the parotid, and its duct of Wharton is about two inches in length. The duct opens on the side of the lingual frænum. The blood-vessels are branches of the facial and lingual. The nerves are those from the submaxillary ganglion, and through this, from the chorda tympani. The sympathetic also supplies this gland.

The sublingual gland rests on the floor of the mouth and is seen beneath the side of the tongue as a ridge. It has a half-dozen ducts called the Rivinian, which open on the ridge that marks the position of the gland on the side of the frænum.

STRUCTURE OF THE SALIVARY GLANDS.

These glands are of the compound racemose variety. The alveolus has a duct ending in it. The alveoli are united by the blood-vessels and a small amount of loose connective tissue with lobules. The alveoli of the salivary glands are divided into two classes, according to the kind of secretion, one kind giving a secretion containing mucin, and the other kind secreting a more watery fluid containing a large amount of serum-albumin; hence the alveoli are mucous or serous. The sublingual chiefly secretes mucus, the parotid chiefly serum-albumin. The submaxillary secretes both kinds. In most of the alveoli of the glands, there are found cells of a kind differing from the mucin-cells, as in the submaxillary of the cat, where they form an almost complete outer layer, next to the base membrane and inclosing the mucin-cells, and are called "marginal cells." In the dog's submaxillary they are seen only as semilunar masses known as the half-moons of Gianuzzi. The lymphatics lie closer to the alveoli than the capillary network of blood-vessels. The lymphatics begin in the form of lacunæ, between and around the alveoli. The nerves pierce the basement membrane and arborize between and around the cells of the alveoli.

PHARYNX.

The pharynx is a funnel-like cavity running from the under-surface of the skull down to the level of the fifth cervical vertebra, where it ends in the œsophagus. There are 7 openings communicating with it: the 2 posterior nares, the 2 Eustachian tubes, the mouth, the larynx, and the œsophagus. The walls of the pharynx are musculo-membranous. The interior is lined with a soft, red, mucous membrane containing many glands. Squamous cells are the chief variety of epithelium lining the mucous membrane. Next is a fibrous coat, then a muscular coat, and outside of this a fibrous investment which attaches it to the skull. The muscular coat includes the superior, middle, and inferior constrictors of the pharynx, which are concerned in deglutition. Lymphoid tissue is very abundant at the upper back part of the pharynx, and a number of lymph-follicles lie between the orifices of the Eustachian tubes, forming the pharyngeal tonsil.

ŒSOPHAGUS.

This tube extends from the fifth cervical down to the ninth dorsal vertebra. It is about nine inches long and less than an inch in diameter. It is narrowest at its commencement and gradually enlarges. It has three coats: the outside, muscular; a middle coat, fibrous; and an internal, or mucous, coat. The muscular coat has a layer of longitudinal fibers and a layer of circular fibers; the upper end of the œsophagus has striated fibers, while the lower half has plain, unstriped fibers. The mucous coat is paler than that of the pharynx and mouth. In ordinary circumstances the mucous membrane is in longitudinal folds. It contains minute papillæ and a squamous epithelium. The nerves of the œsophagus are the vagus and the sympathetic.

THE MECHANICAL PROCESSES OF DIGESTION OCCURRING IN THE MOUTH, PHARYNX, AND ŒSOPHAGUS.

MASTICATION.

This is a voluntary act whereby the food is comminuted by the teeth, jaws, and muscles concerned in this act, aided by the tongue, palate, cheeks, and lips. The bulk of the work is accomplished by the biting and grinding movements of the lower teeth against the upper ones.

From the manner of its articulation with the skull the lower jaw is capable of performing three primary movements, together with combinations of these same, viz.: up and down, side to side, with projection and retraction. The muscles concerned in producing these movements are the masseter, temporal, and internal pterygoids, which *raise* the lower jaw; the inferior maxillary division of the fifth nerve innervates them. The depression of the jaw is accomplished mainly through the action of the digastric, aided considerably by gravity. The side-to-side, or lateral, movements are due to the separate action of the external pterygoids. Their united contraction gives projection of the lower mandible, to be retracted by a part of the temporal muscle. The innervation of the pterygoids is also by the inferior division of the fifth.

Mastication is particularly important when solid and fibrous foods are eaten, to prepare them by comminution for the fermentative action of the various digestive fluids. When improperly performed repeatedly, a severe form of dyspepsia ensues.

During mastication there is performed a separate and distinct act, *insalivation,* or the mixing of the food with saliva. By means of it, the dry, hard portions of food are moistened and softened the better to fit them for swallowing; at the same time the mucous membrane is lubricated to allow free movement of the food over its surface, and the surfaces of the teeth are freed from accumulations of food during mastication, which otherwise would collect and impede its progress. A fever patient attempting to swallow a dry cracker affords ample illustration of the mechanical value of the saliva during mastication.

DEGLUTITION.

The swallowing of the food, which has been named the act of *deglutition,* is performed by the aid of the tongue, fauces, pharynx, and the œsophagus or gullet. For the purpose of description only, since the process in reality admits of no lines of distinction, this act is usually said to comprise *three stages: first,* that in which the food is forced backward from the mouth, through the fauces into the pharynx. This act is voluntary, though usually performed unconsciously, being ascribed to the movements of the tongue itself. The *second* stage is that in which the bolus is made to travel along the middle and lower part of the pharynx to the œsophagus. This second act is more complicated and requires quicker movements, because the nasal and laryngeal orifices are open, but past which the food must go without entering. The main motive power for this performance is gained by the contractions of the three constrictors, aided by the synchronous action of other muscles, whose duty is to occlude temporarily the nasal and laryngeal openings. The opening into the nasal cavity is closed by the elevation of the soft palate, uvula, and the contraction of the posterior pillars of the fauces. Just above the laryngeal opening and at the base of the tongue is a small, leaf-shaped piece of cartilage, the epiglottis. It was formerly believed that the laryngeal orifice was guarded during deglutition by the retraction of the tongue pressing down the epiglottis to fit it firmly. But, as removal of the epiglottis did not interfere with normal swallowing, it was learned that the real safeguard was the contraction of the *aryteno-epiglottic folds.* The *third* stage is that in which the bolus descends along the œsophagus to enter the stomach. This stage is performed by the intrinsic contractions of the muscular fibers of the œsophagus-walls. As is known, its muscular fibers are arranged in two layers: one circular, the other longitudinal. The upper third is composed of striated muscle-fibers, the lower two-thirds of plain, or unstriped, variety. Accordingly in the upper third the movement of the bolus is more rapid than in the lower two-thirds. The movement through the œsophagus is that known as *peristaltic*, or vermicular. The second and third stages of deglutition are involuntary. When the death-rattle occurs it is caused by the pharynx not contracting around the bolus.

Swallowing of Fluids.

From what has been said previously it will be readily perceived that the act of deglutition of both liquids and solids is a muscular act, and not, therefore, dependent upon gravity. Thus, horses and many other animals drink with their heads low, so that the fluid must needs be forced up an inclined plane to reach their stomachs. Sometimes jugglers, while standing upon their heads, perform the feat of drinking.

The deglutition of boli or food was, for convenience, divided into three stages, but so quickly is the passage of liquids accomplished that physiologists are able to recognize but one movement. We are indebted to the experiments and observations of Kronecker and Meltzer for an explanation of this process; according to them, there is an action resembling, in the main, that of a force-pump, whereby the mass of liquid is propelled with extreme rapidity through the pharynx and œsophagus.

It is by the contraction of the two *mylohyoids* that the liquid is put under high pressure and shot along in the direction of least resistance: through the pharynx and œsophagus. This pair of muscles is greatly aided by the simultaneous action of the two hyoglossi muscles. These two pairs of muscles, by acting in unison, form a sort of diaphragm to push the root of the tongue backward and downward, at the same time performing a force-pump action upon the liquid to be swallowed. So quickly is the passage of the liquid accomplished that the pharyngeal and œsophageal muscles have not time to contract about the mass of liquid; in fact, they are inhibited during the passage of liquids through their respective channels. After the liquids arrive in the stomach the act of deglutition ensues for the purpose of removing the liquids adhering to the walls of œsophagus.

This statement is substantiated very strikingly in cases of poisoning by carbolic acid and other corrosive substances. The mouth and tongue, from longer contact, are always burned, while the pharynx and œsophagus may escape altogether, or, at most, are but slightly burned. The escape of the latter is due to the rapid transit of the corrosive substance through them. However, the cardiac entrance of the stomach is always very much corroded before the sphincter relaxes for admission into the stomach.

When the ingested food has been thoroughly insalivated or is semisolid, there begins to be a departure from the three-stage act toward the force-pump action of liquids. When the food is very much liquefied the latter action is very prominent; so that any fixed line for the swallowing of food or liquids does not exist.

Nervous Control of Deglutition.

Deglutition is a reflex act. Every reflex act requires an afferent set of sensory nerves, a reflex center, and an efferent set of motor nerves, that of swallowing no less so than any other. The sensory nerves have their terminations in the mucous membrane of the pharynx and œsophagus, including branches of the *glosso-pharyngeal* to the tongue and pharynx, branches of the *fifth* to the soft palate, and the *superior laryngeal* branch of the vagus innervating the glottis and epiglottis. The reflex center lies somewhere forward in the medulla. The *efferent* nerves are: branches of the *fifth,* which supply the digastric, mylohyoid, and muscles of mastication; the *facial,* which supplies the levator palati; the *glosso-pharyngeal* supplies the muscles of the pharynx. Stimulation of central end of the superior laryngeal calls out an act of deglutition. Stimulation of central end of the glosso-pharyngeal arrests it. The *inferior laryngeal branch* of the vagus innervates the muscles of the larynx, while the *hypoglossal* is distributed to the intrinsic muscles of the tongue. Division of the two vagi is followed by paralysis of both œsophagus and stomach, with a very firm contraction of the circular band of fibers guarding the cardiac orifice. Therefore these nerves send *motor* fibers to the œsophagus and stomach, but *inhibitory* ones to the cardiac sphincter. So firm is the tetanic contraction of the sphincter that if food is swallowed after division of the vagi it accumulates within the œsophagus, no part of it passing into the stomach.

The act of swallowing inhibits the vagus center, for a single act of deglutition increases the pulse-rate. This influence upon the heartbeat is dependent upon neither the amount, character, nor temperature of the bolus swallowed. It is influenced only by the reflex act and the summation of other acts. It also has an inhibitory influence upon the respiration. This is very evident during rapid drinking in an animal with a tracheotomy tube. For increasing the activity of the heart's action a tablespoonful of water taken in a large number of swallows is more beneficial than a glass of wine taken in one swallow.

THE CHEMICAL CHANGES OCCURRING IN THE MOUTH DURING DIGESTION.

As before stated, the chief aim of digestion in the animal economy is the reduction of the alimentary substances into a soluble and absorbable condition, so they can pass through the various animal membranes and become components of the tissues and blood of the body. No matter how soft, through the influence of insalivation, or finely divided and triturated by reason of mastication, the food may be, it cannot become a constituent of the body until it has been acted upon chemically and dissolved by the various ferments present in the different digestive fluids.

When food enters the mouth, the commencement of the digestive tract, the first digestive fluid that it comes in contact with is the saliva. Besides its mechanical functions of moistening and softening the food to render easier the task of swallowing it in the form of boli, it performs other duties of a *chemical* nature.

First, by reason of its watery base, it has the power to dissolve saline substances, the organic acids, alcohols, sugars, and a few other substances soluble in water.

Secondly, it has the power to transform certain materials, as starches, into maltose, a form of sugar. The starch must have its cellulose coat dissolved by boiling, however, for the ferment in saliva will not act readily upon cellulose. The active, transforming principle in saliva is an unorganized ferment, or enzyme, to which the name *ptyalin* has been given. The conversion of starch into dextrin and maltose by it is known as the *amylolytic* action of saliva. Its action is by mere contact, for no appreciable change in quantity or character is noted in it after its functions are performed, and so active is it that it is able to convert two thousand times its own weight of starch into dextrin and maltose.

The word "ase" is given to an enzyme, and this is preceded by the name, or its root, of the substance upon which it acts. Thus, ptyalin, an amylase (amylum, starch), breaks up starch into maltose. Thus, saccharase or invertase of the small intestines acts on saccharose and produces glucose and fructose, which can be absorbed and assimilated.

The bacillus coli communis, a normal denizen of the large intestine, secretes lactase, which breaks up lactose.

Lipase or steapsin breaks up fats into fatty acid and glycerin.

We have proteases which break up the proteids into peptones, and the peptones into amino-acids. The proteases are pepsin, trypsin, erepsin, and enterokinase.

We have the coagulases, such as rennin and the fibrin ferment (thrombase).

Certain fungi (Russula and Boletus), when cut, have a blue or black color on their surface, due to a melanin formed by an enzyme, tyrosinase, acting on tyrosin. Both these bodies are free in the plant, but come in contact when the tissues are injured. Tyrosinase exists in animal tissues. Within recent times it has been found that maltase, when added to a 40 per cent. solution of glucose, reverses its action and builds up maltose until 14 per cent. of maltose is formed, when it stops. This resembles a chemical action—constant breaking down of maltose, but constant building up at the same rate. Lipase has a similar reversing action, but it has not been found true for other enzymes. Hence maltase and lipase are destructive and constructive, and may be agents by which the cell maintains its nutritive balance between its protoplasm and the surrounding extracellular lymph.

The hydrolytic action of enzymes upon the sugars depends upon their stereo-isomeric form. From glucose and methyl-alcohol there results Alpha-methyl-glucoside and Beta-methyl-glucoside. If the enzymes of yeast are tested on these two compounds, which differ only in stereo-chemical relationship, it is found that only the Alpha-modification is hydrolyzed. The Beta one is quite resistant. Hence, according to Fischer's statement, the ferment and its substance must fit like the lock and key, or the reaction does not occur.

The action of ferments is to quicken a process of hydrolysis which, without their presence, would take a long time for its accomplishment.

Ferments do not initiate a chemical action, but alter the velocity of reaction, which occurs in their absence, only then much more slowly or much more quickly.

Saliva, as it appears in the mouth, is a thick, glairy, generally frothy and turbid fluid. It is a mixed fluid, its secretions being derived from the parotid, submaxillary, and sublingual salivary glands, and contains mucin procured from the labial, lingual, and buccal glands. Then, too, it contains some *débris* of food, bacteria, and the so-called salivary corpuscles. Its thick, ropy nature is due to the presence of the mucin in it. Normal saliva is alkaline in reaction, but in some forms of dyspepsia it becomes somewhat acid. The specific gravity ranges from 1.002 to 1.006.

The amylolytic action of saliva is sensitive to changes of temperature, a low temperature either retarding its action or stopping it altogether, while increased temperature causes greater activity until 40° C. is reached, which is considered the optimum point. Above that mark the heat becomes injurious.

During the proper mastication and insalivation of a mouthful of food, there occurs, to the starches present, a splitting up into dextrin and maltose; the dextrin is later converted into maltose also. This occurs more quickly with erythrodextrin, which gives a characteristic red color with iodine, than with achroödextrin, which gives no color with iodine.

The amylolytic action of saliva is best favored by a neutral medium, although it can take place when the environment is slightly alkaline or acid. The slightest quantity of free acid in excess stops its action at once. Its normal condition in the mouth is slightly alkaline or neutral. In these media the splitting-up process takes place quickly; but, since the food is usually held in the mouth for so short a time, all the starches cannot be transformed during the period of mastication. As the gastric juice contains free hydrochloric acid, it has been generally thought that immediately the bolus of food comes in contact with the gastric juice the ptyalin of the saliva is killed and its amylolytic action stopped. Recent researches have proved that the transforming continues in the stomach for some time after its entry, the time ranging from fifteen to thirty minutes. That is, until (*a*) the alkalinity of the saliva has been neutralized and (*b*) until a trace of free hydrochloric acid remains in excess. According to Veldin, free hydrochloric acid does not occur in the stomach until about three-fourths of an hour after a meal.

The action of saliva upon starch is very readily seen by test-tube experimentation. In a tube is placed a quantity of boiled starch, which is viscid and gelatinous in nature and rather turbid in appearance. That it is true starch may be shown by the iodine test, a blue color resulting. With the starch in the tube is mixed a quantity of saliva. Soon there is a marked change: the solution becomes more watery and thinner and the turbidity disappears. On boiling a portion of this transparent solution with Fehling's solution a cuprous oxide is precipitated, showing the presence of sugar in the form of dextrose or maltose. The action of ptyalin on starch is as follows:—

$$\underset{\text{Starch.}}{C_{12}H_{20}O_{10}} = \underset{\text{Dextrin.}}{C_{12}H_{20}O_{10}}$$

$$\underset{\text{Dextrin.}}{C_{12}H_{20}O_{10}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

Ptyalin has also a reversible action; that is, forms starch at the same time it is breaking it down. Saliva also has a maltase which splits maltose into two molecules of dextrose:—

$$\underset{\text{Maltose.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + C_6H_{12}O_6$$

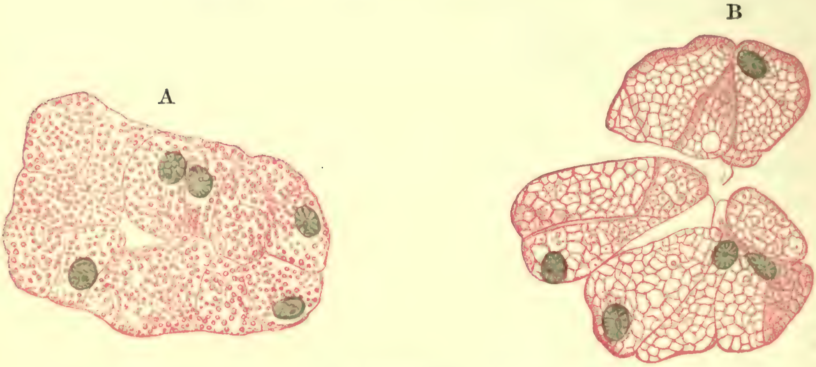

Fig. 11.—Parotid of Cat. (L. Müller.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

A, After fasting 24 hours. *B*, During activity.

Maltase also has a reversible action. The saliva also contains traces of an inorganic substance, potassium sulphocyanide. Tincture of iron stains it red.

In the resting serous gland when stained with carmin it is found that the cells are pale, with but little color, and contain a few minute granules. The nucleus is small sized, without a nucleolus; in shape, irregular, and red stained. The shrinking of the nucleus is well marked. In the active stage the cells are smaller, the nuclei are round, with sharp walls containing nucleoli. The contents of the cell are turbid, due to the lessening of the clear substance and an increase of granules. The carmin stains the cells deeper.

The salivary glands are greatly influenced by nervous activity.

The submaxillary is supplied by the chorda tympani, which contains two kinds of fibers: the secretory and the vasodilator. If you give atropine you can paralyze the endings of the secretory fibers while the vasodilators still continue their activity. Injection of sodium bicarbonate into the duct of Wharton arrests the action of the secretory fibers and leaves intact the vasodilators. Pilocarpine and muscarine increase the flow of saliva by stimulating the endings of the chorda tympani and will *remove* the paralysis caused by atropine. Opium makes the mouth dry by acting on the center of salivation. The salivation by mercury is due to excessive metabolism of the gland-cells themselves. When the chorda is stimulated by electricity, the pressure in the excretory duct is greater than the blood-pressure of the animal. During this stimulation the temperature is elevated. When the chorda tympani is stimulated the blood-vessels of the gland dilate and the veins are red and pulsate because the arterial blood rushes rapidly through them. The antagonistic nerve which slows the secretion of saliva, both in the submaxillary and parotid gland, is the cervical sympathetic. At the same time, owing to its vasoconstrictors, the blood-vessels are contracted. Hence in the submaxillary we have as a secretory nerve

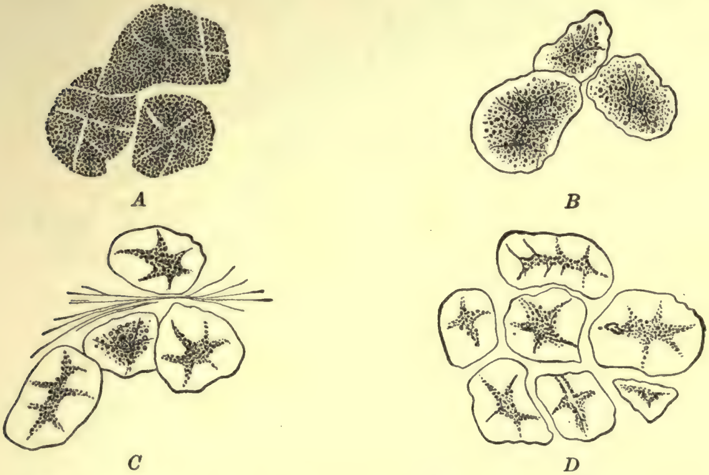

Fig. 12.—Parotid of a Rabbit in Fresh State. (LANGLEY.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

A, Resting gland. *B*, Gland after a small dose of pilocarpin. *C*, Irritation of cervical sympathetic. *D*, After strong irritation of cervical sympathetic.

the chorda tympani; in the parotid the auriculo-temporal. The nerve playing against them both is the cervical sympathetic.

The parotid gland receives fibers from the bulbar origin of the autonomic system through the glosso-pharyngeal, then by the tympanic branch of this nerve or nerve of Jacobson; then by the small superficial petrosal nerve through which it reaches the otic ganglion; then by the post-ganglionic fibers by the auriculo-temporal branch of the inferior maxillary of the fifth nerve to the parotid. It receives, as a sympathetic nerve, post-ganglionic fibers from the superior cervical ganglion, which reach here by the cervical sympathetic.

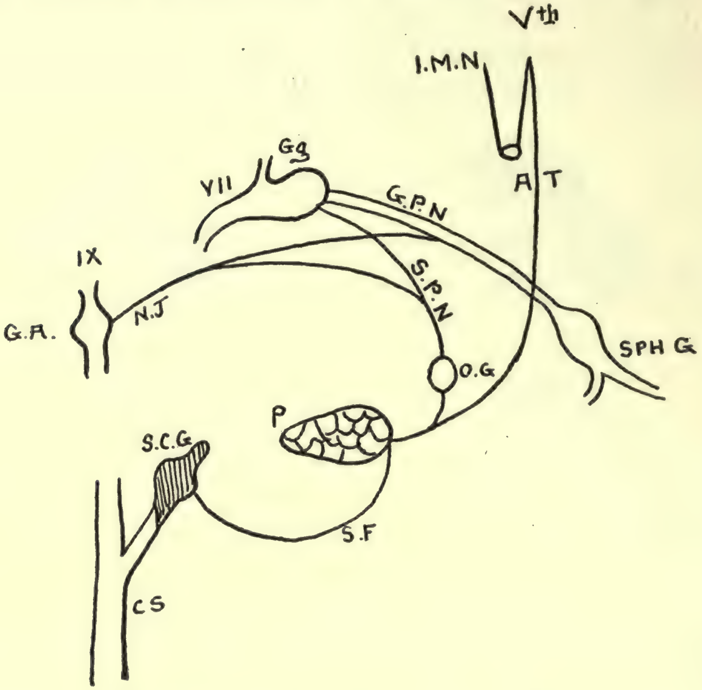

Fig. 12a.—Schema of Nerves of Parotid Gland.

GA, Ganglion of Andersch. *IX*, Ninth cranial or glosso-pharyngeal nerve. *NJ*, Nerve of Jacobson, or tympanic nerve. *VII*, Facial nerve. *Gg*, Geniculate ganglion. *GPN*, Great petrosal nerve. *SPN*, Small petrosal nerve. *V*, Fifth cranial nerve. *IMN*, Inferior maxillary nerve. *AT*, Auriculo-temporal. *OG*, Otic ganglion. *SphG*, Spheno-palatine ganglion. *CS*, Cervical sympathetic. *SCG*, Superior cervical ganglion. *SF*, Post-ganglionic sympathetic fibers. *P*, Parotid.

The submaxillary and sublingual glands receive their autonomic fibers by the chorda tympani branch of the facial nerve, which, after running into the lingual of the fifth cranial nerve for a short length, sends its secretory and vasodilator fibers to the sublingual ganglion of Langley to the sublingual glands, whilst the others pass by the sublingual ganglion to the submaxillary gland.

The submaxillary ganglion lies at the point of departure of

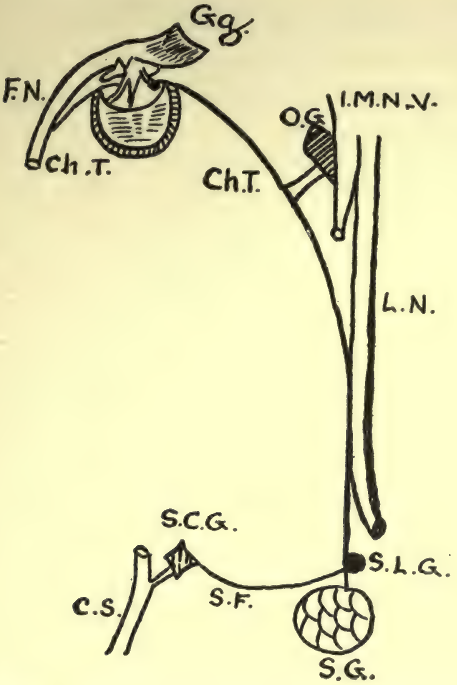

Fig. 12b.—Schema of Nerves of Submaxillary Gland.

***FN*, Facial nerve. *ChT*, Chorda tympani. *Gg*, Geniculate ganglion. *OG*, Otic ganglion. *IMNV*, Inferior maxillary of the fifth. *LN*, Lingual nerve. *SLG*, Sublingual ganglion. *SG*, Submaxillary gland. *CS*, Cervical sympathetic. *SCG*, Superior cervical ganglion. *SF*, Post-ganglionic sympathetic fibers. The chorda tympani also contains vasodilator fibers for the gland and the cervical sympathetic contains vasoconstrictor fibers.**

the chorda tympani from the lingual, but only the nerves going to the sublingual of Langley's gland are connected with it. The sympathetic nerve, as with the parotid, passes up the cervical sympathetic to the superior cervical ganglion, and then to the submaxillary and sublingual glands.

The afferent fibers of the salivary glands are the taste fibers in the chorda tympani and glosso-pharyngeal, with the branches of the lingual. The chorda tympani fibers run to the geniculate ganglion and enter the brain with the fibers of the portio intermedia of the seventh nerve.

The afferent fibers of the glosso-pharyngeal go back to the otic ganglion, then by the small superficial petrosal nerve and tympanic nerve to the nucleus of the glosso-pharyngeal.

Trophic and Secretory Fibers.

There are two kinds of fibers going to the salivary glands. If the chorda be stimulated, it is found that the saliva contains more water and salts in proportion to the organic matter than existed before. If previous to the stimulation, the gland was at rest and not exhausted, the increase of the stimulation at first causes a rise in the percentage of organic constituents, and this rise is more notable than in the case of the salts. Hence Heidenhain held that two kinds of nerve-fibers were distributed to the salivary glands. One governs the secretion of water and salts, the other governs the formation of the organic constituents of the saliva; the former he called secretory fibers, the latter trophic. The sympathetic mainly has trophic fibers, the chorda chiefly secretory fibers.

Pawlow has shown in the dog that the submaxillary gland reacts to a great number of stimuli, such as the sight of food (psychical secretion), chewing of meats, and acids. The parotid reacts only when dry food, dry bread or dry meat, is placed in the mouth. Foods with a large amount of water excite a little flow of saliva, whilst dry foods cause a more abundant flow. Here is an adaptive capacity of the nerves of the salivary glands to the character of the food chewed. The reflex center for the salivary secretion is situated in the medulla oblongata, near the origin of the ninth and seventh cranial nerves. The afferent nerves are the nerves of taste, the chorda tympani and the glosso-pharyngeal and sensory branch of the trigeminus; the efferent nerves are the auriculo-temporal and chorda tympani.

GASTRIC DIGESTION (DIGESTION IN THE STOMACH).

The stomach is the principal organ of digestion. As we know, digestion has for its aim the rendition of the organic and inorganic substances ingested from the external world into such a condition that they can readily mix with the blood and so be introduced into the living tissues of the body. For no animal can exist which does not receive materials for its support from the environing media.

To accomplish this aim both chemical and mechanical changes are closely interwoven. In the stomach, as one of the principal organs, is performed a large and important share of the whole digestive process; as it were, it is one of the large departments of a mechanical and chemical laboratory or establishment in which every department is working toward a definite end: the digestion of the food. Unlike the amylolytic changes of the saliva, which best occur in an alkaline solution, stomachic digestion is an acid digestion.

The stomach is the first organ into which the food passes as it leaves the œsophagus. It is the most enlarged or dilated portion of the entire alimentary canal, being located in the left hypochondriac, epigastric, and right hypochondriac regions. It is a large muscular pouch, and extends from the œsophagus to the small intestine. The greater extremity of the stomach is to the left and communicates with the œsophagus by the cardiac orifice. The pyloric end is the lesser extremity, and at the right communicates with the small intestine by the pyloric orifice.

The fundus is the greater extremity of the stomach, and projects several inches to the left of the œsophagus. The lesser extremity for about two inches of its length is slightly constricted, and is called the pyloric antrum. The pyloric orifice is the entrance to the duodenum, and is about a half-inch in diameter. It contains the pyloric sphincter, or valve.

STRUCTURE OF THE STOMACH.

The stomach has four coats: from the outside, serous, muscular, fibrous, and mucous. The serous coat is derived from the peritoneum. The muscular coat contains three layers of unstriped muscular fibers. The layer of longitudinal fibers is continuous with that of the œsophagus, from which it radiates over the stomach.

The middle layer is composed of circular fibers. These circular fibers gradually accumulate toward the pyloric extremity and form a thick band known as the pyloric sphincter. The internal layer consists of oblique fibers. The submucous coat is made up of areolar tissue and forms an extensible layer upon which the strength of the stomach mainly depends. The mucous membrane of the stomach is soft to the touch and of a pale-pinkish color. Under excitement it becomes reddened. During digestion and when inflamed it has a deep-red hue. It is thin at the fundus and gradually thickens toward the pyloric extremity. In this place it ordinarily is in a state of wrinkles or rugæ, which are longitudinal in great part. At the pyloric orifice a thick circular fold acts as a part of a valve called the pyloric valve.

Structure of Mucous Membrane.

Upon an examination with a feeble magnifying power there is found on the mucous membrane a great number of depressions about $^1/_{200}$ inch in diameter, which are the openings of the glands of the stomach. The mucous membrane is lined with a columnar epithelium. The tubular glands of the stomach are placed side by side and number several millions. These glands have a basement membrane, which separates the glands from one another and in which the capillaries spread a fine network over the tubules. They have also a blind end. There are two kinds of gastric glands: the cardiac and the pyloric. The pyloric glands have at their mouth an epithelium which is a continuation of the columnar epithelium of the stomach. In the tubules the epithelium is shorter and more cubical and granular. In the fundus glands and cardiac glands the epithelium is composed of short columnar cells, and these cells have

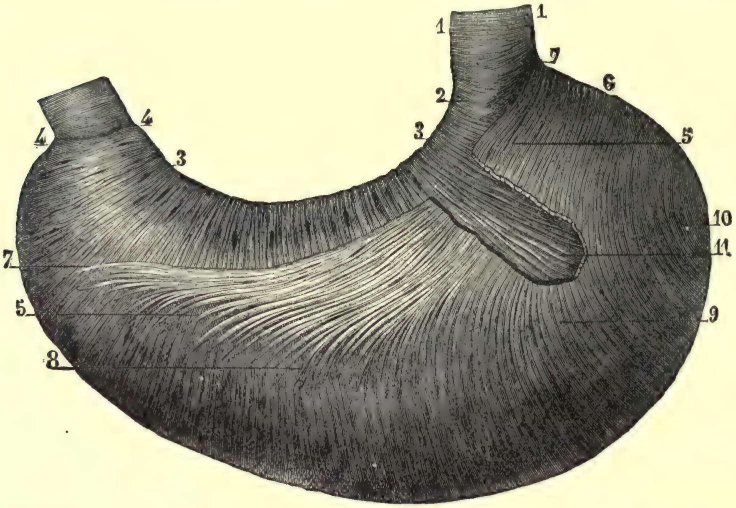

Fig. 13.—Human Stomach. (After SAPPEY.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

1, Œsophagus. 2, Circular fibers at œsophageal opening. 3, 3, Circular fibers at lesser curvature. 4, 4, Circular fibers at the pylorus. 5, 5, 6, 7, 8, Oblique fibers. 9, 10, Fibers of this layer covering the greater pouch. 11, Portion of the stomach from which these fibers have been removed to show the subjacent circular fibers.

coarser granules than the pyloric glands. These are the central, or adelomorphous, cells. Between these cells and the basement membrane there is another cell, oval in shape, with a distinct oval granular nucleus, called the parietal, or delomorphous or oxyntic, cells.

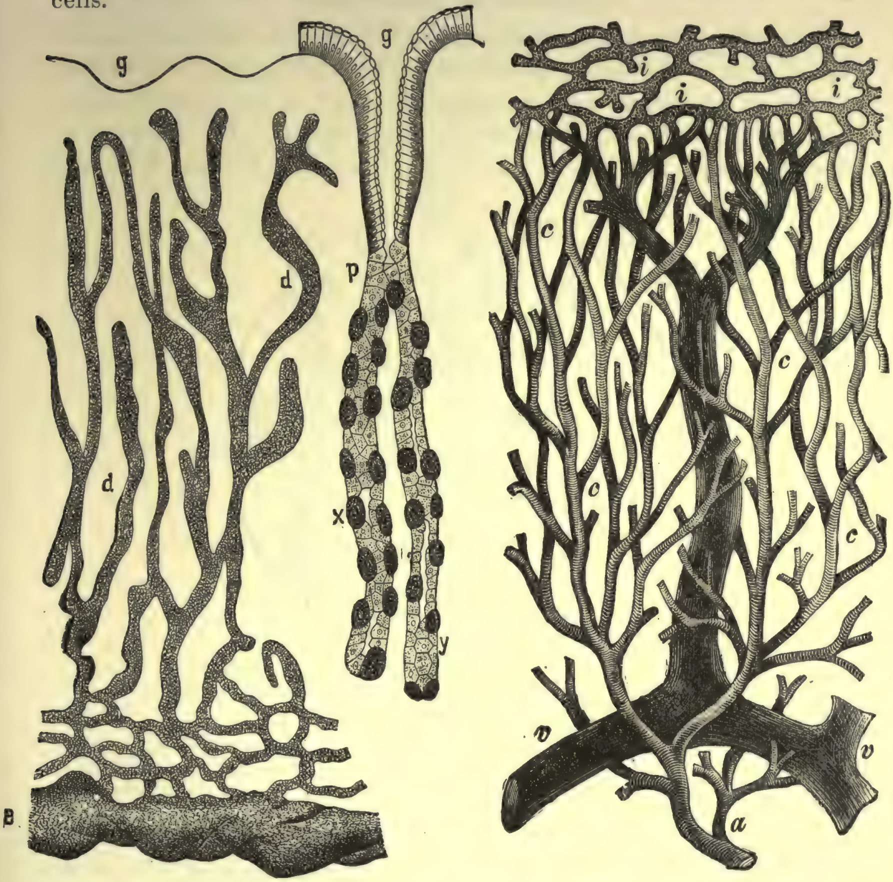

Fig. 14.—Vertical Section through the Gastric Mucous Membrane. (LANDOIS.)

g, g, The crypts of the surface. *p*, The mouths of the peptic tubules (fundus glands) with parietal cells (*x*) and chief cells (*y*). *a, v, c, c*, Artery, vein, and capillaries of the mucous membrane. *i*, Capillary network for the passage of the mouth of the gland-duct. *d, d*, The lymphatic vessels of the mucous membrane, passing over, at *e*, into a large trunk (semidiagrammatic representation).

The blood-vessels of the stomach are derived from the three divisions of the cœliac axis. The veins are the tributaries of the portal vein, and contain numerous valves. The nerves are the vagus and sympathetic. Numerous small gangliated plexuses are found: those of Meissner in the submucous coat, like those in the intestine; and Auerbach's, between the muscular fibers, also found in the intestine.

Movements of the Stomach.

Dr. Beaumont, in experiments upon a human stomach, ascertained that a very feeble peristaltic condition begins at the cardiac orifice, to proceed toward the pylorus by way of the greater curvature, for only along it is any movement apparent. The wave grows stronger until the special band separating the antrum from the fundus is reached, when the contraction becomes so strong that the stomach presents an hour-glass appearance. Immediately the entire antrum contracts at one time as a unit; so that, if the contents are properly acted upon by the gastric secretion, they are propelled by this movement through the pylorus into the duodenum. If, as very frequently happens, the semi-liquid mass contains solid portions of too great bulk to pass through the opening, a muscular wave is set up in the opposite direction. The direct result of this is to force into the fundus through the now relaxing temporary sphincter the food-mass, and there the whole process is begun again. These movements occur with a certain degree of regularity and rhythm,

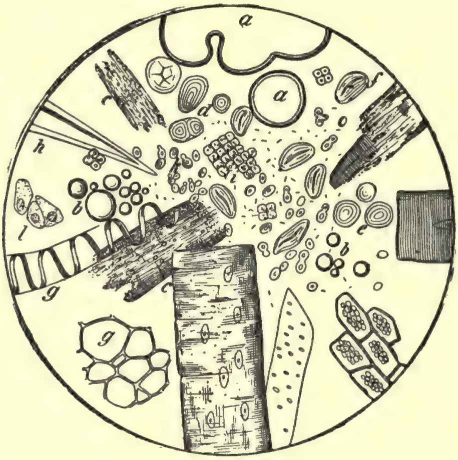

Fig. 15.—Gastric Contents. Collective Microscopic Picture. × 350. (Lenhartz.)

a, Air-bubble. *b*, Oil-droplet. *c*, Muscle-fiber, nearly digested. *d*, potato starch. *e*, Swollen rye-starch. *f*, Leguminous starch. *g*, Various vegetable cells. *h*, Vegetable hair. *i*, Sarcina. *k*, Yeast fungi. *l*, Gastric gland-cells.

once in about every two or three minutes; the time and regularity are, however, much influenced by the quantity and quality of the food ingested. As a result of these combined movements, not only is the chymified food propelled into the duodenum, but there are set up regular currents among the contents.

Dr. Cannon has studied the movements of the stomach in cats by means of the Roentgen rays. He states that the stomach consists of two physiologically distinct parts: the pyloric part and the fundus. Over the pyloric part while food is present constriction waves are seen continually coursing toward the pylorus. The fundus is an active reservoir for the food, and squeezes out its contents gradually into the pyloric part. The stomach is emptied by the formation between the fundus and the antrum of a tube along which the constrictions pass. The contents of the fundus are pressed into the tube and the tube and antrum slowly cleared of food by the waves of constriction. The constriction waves have three func-

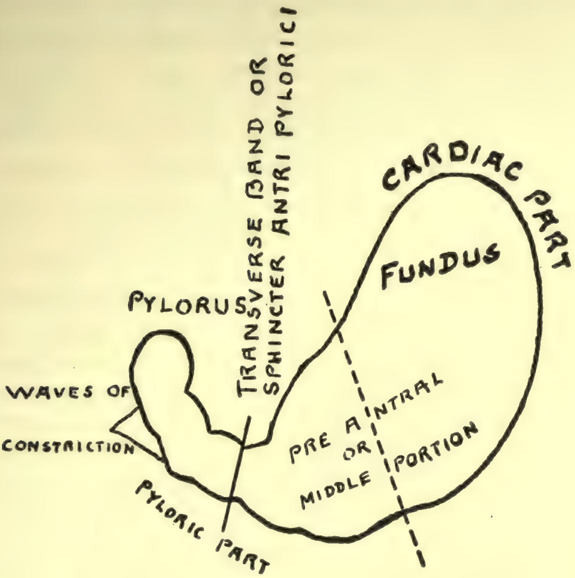

Fig. 15a.—Functional Divisions of the Stomach.

The fundus serves as a reservoir in which the food is gradually mixed with the gastric juice. The fundus squeezes the food into the tube between the fundus and antrum, called the pre-antral or middle portion. This pre-antral tube has muscular constrictions about every fifteen seconds. In the pyloric end the forcible and active movements mix the food with the gastric juice, rubbing it down to a fluid, which is gradually forced out into the duodenum. (HUTCHISON.)

tions: the mixing, trituration, and expulsion of the food. The stomach movements are inhibited when the cat shows anxiety, rage, or distress. Cannon has observed in cats that carbohydrate food appeared in the intestine in ten minutes, while proteid did not leave for an hour. Proteids also remained in the stomach twice as long as the fats.

CLOSURE OF THE PYLORUS.

Each time the acid chyme escapes, it sets up a reflex act which temporarily occludes the pyloric orifice, and, at the same time, inhibits the propulsive movements of the organ. The acid mass of chyme escaping the pylorus, excites an increased secretion of pancreatic juice and the acid is gradually neutralized. When this is accomplished the escape of further acid chyme is permitted. This regulatory action prevents disorder in the progress of digestion and at the same time insures regularity in the transition from the acid gastric digestion to the alkaline intestinal one. The opening of the pylorus is due to the presence of free acid at the pylorus. Both the closure of the pylorus and the opening of the pylorus can ensue without the intervention of the nerves going to the stomach. The acidity of the contents of stomach keeps the cardia closed.

THE NERVOUS CONTROL OF THE STOMACH.

As known to-day, the nerve-supply to the stomach is from both the cerebro-spinal system and the sympathetic; its connection with the former is through the medium of the vagi, with the latter by the splanchnics through the solar plexus. The fibers of both systems distributed to the gastric muscles are nonmedullated. The functions of the vagi have been conclusively proved to be motor, for when they are stimulated by chemical, thermal, or other irritants, there results a peristalsis throughout the whole viscus. On the contrary, the fibers from the sympathetic system are inhibitory; when they are stimulated, peristalsis is stopped and there is dilatation of the sphincter pylori. The stomach also has movements of its own independent of the central nervous system.

THE GASTRIC JUICE.

Gastric juice mixed with food and water can readily be obtained by the gastric sound or stomach-pump. Pure gastric juice cannot be procured thus, for when the stomach is empty the flow of gastric juice ceases and any surplus remaining in the stomach seems to be reabsorbed. Its flow is begun again only as the result of stimuli;

the natural ones and those producing what alone may be termed *normal* gastric juice, are food and drink.

Normal gastric juice has been procured by feeding an animal a fictitious meal. In this process the food swallowed does not reach the stomach, but passes out of the œsophagus through a fistula. The eating has the power to excite reflexly the flow of the secretion.

Gastric juice thus obtained from a dog is a "clear, colorless, limpid fluid, very acid, and peptic in nature. The liquid is practically odorless; if there is any odor at all present it is characteristic of the animal. Its specific gravity differs very little from that of water" (1002.5). The quantity of gastric juice secreted daily is about one-tenth the weight of the body.

The largest constituent of the gastric juice is water. In man and animals it is remarkable to note the small quantities of solid matters present and then view the immense amount of work done by them in the digestive processes. Of the solids present, about half are inorganic salts; the remaining portion comprises the organic ferment, or enzyme, present in gastric juice—pepsin.

The reaction of gastric juice is undoubtedly acid, caused by the presence of free hydrochloric acid (0.2 per cent.). In the pure secretion, free from food, it has been demonstrated that the only acid is hydrochloric. Acid is necessary, for pepsin, the active ferment of gastric juice, can act only in an acid medium. During digestion, lactic, acetic, butyric, and other acids are often present, due to putrefactive changes and the presence of bacteria. Pepsin can act in the presence of these acids as media, but not very well.

Schmidt's analysis of the composition of gastric juice is as follows:—

Water	994.40
Solid residue	5.60
	1000.00
Organic matter:	
Pepsin	3.19
Inorganic matter:	
Chloride of sodium	1.46
Chloride of potassium	0.55
Chloride of calcium	0.06
Free hydrochloric acid	2.00
Phosphate of calcium Phosphate of magnesium Phosphate of iron	0.12

Secretion of the Gastric Juice.

Imbedded in the mucous membrane of the walls of the stomach are two sets of secretory apparatus: the *cardiac* and *pyloric glands.* Naturally the products of these glands differ somewhat in their characters; so that the gastric secretion as a unit is a mixed body, or solution. This "mixed" gastric juice is a secretion compound of a very small percentage of free hydrochloric acid together with the proteolytic ferment, pepsin, in a rather saline solution. We know that the pepsin, for instance, of the gastric juice, is not found as such in the blood, requiring only to be filtered from the same for use, but that it is the result of the activity of the cells and yielded by them.

A characteristic microscopical feature of the cells of secretory glands in general is that the protoplasmic portions are crowded with fine granular bodies before secretion, but that during and particularly after secretion their numbers are very perceptibly diminished. From this it was inferred that, while the granules might not in themselves represent the important ingredients of the various secretions, yet they were responsible and directly concerned in their manufacture.

The cardiac glands are composed of two distinctive types of cells: columnar epithelium lining the lumen and the large spherical or oval cells located on the periphery. The former are termed *chief,* or *central,* the latter *parietal,* cells.

The pyloric glands are constructed of but the one kind, epithelial in nature, similar to those found in the cardiac cells and termed *chief,* or *central.*

The central cells of both the cardiac and pyloric glands are found to be heavily charged with minute granules before digestion; in fact, such numbers are present as to interfere with the staining of the cells with aniline dyes, because of the protoplasm being obscured. During secretion some of the granules are discharged into the lumen, presumably through the protoplasmic movements of the cells as agents or media. After digestion, therefore, the cells show a difference, principally in that there is a decrease in the number of granules present, manifested by either a clear path along the periphery or by a shrunken appearance of the cells with fewer granules. The material for the formation of these granules is taken by the cells from the lymph which constantly bathes them, and through the influence of the protoplasm is manufactured into granules.

The central are the cells which are directly concerned in yielding the very important and proteolytic element of the gastric juice, the pepsin. Without its presence in an acidulated medium, the normal processes of proteolysis are unable to be accomplished in the stomach. These granules are not pure pepsin to be passed along the lumen and so enter the composition of the gastric juice, but are, rather, a zymogen substance acting as a precursor, which is readily converted into pepsin through the influence of the acid. To this intermediate substance has been given the name *pepsinogen.*

The large oval or *parietal cells* also contain granules which are very few in number and small in size, though quite distinct. These are very constant in quantity, the cells showing mainly differences in size. Thus, before secretion, they are swollen; afterward, shrunken. They are frequently termed *oxyntic,* as they are thought to secrete hydrochloric acid, one of the essential compounds of the gastric secretion. The exact process, however, is still shrouded in mystery. It is thought to result from a simple process of diffusion in the parietal cells of chlorides taken from the blood, for during secretion the quantity of chlorides leaving the blood through the kidneys is diminished. Maly's theory with regard to this is very satisfactory. In it he claims that the acid originates by the interaction of the calcium chloride with the disodium hydrogen phosphate of the blood. The interaction is simplified by the following equation of Maly's:—

$$\underset{\substack{\textbf{Disodium}\\\textbf{hydrogen}\\\textbf{phosphate.}}}{2Na_2HPO_4} + \underset{\substack{\textbf{Calcium}\\\textbf{chloride.}}}{3CaCl_2} = \underset{\substack{\textbf{Calcium}\\\textbf{phosphate.}}}{Ca_3(PO_4)_2} + \underset{\substack{\textbf{Sodium}\\\textbf{chloride.}}}{4NaCl} + \underset{\substack{\textbf{Hydro-}\\\textbf{chloric}\\\textbf{acid.}}}{2HCl}$$

The stimulus to the secretion of HCl is the presence of free chlorine ions on the inner side of the stomach's glands. If chlorine ions are absent in the stomach then no HCl is formed. If the animal be fed on bromides instead of chlorides, then hydrobromic acid is formed in place of HCl. The glands of the stomach do not permit chlorine ions to go through them, whilst free hydrogen ions which exist in the blood go through the glands into the stomach and HCl is formed.

Formed in the central cells is another zymogen than pepsinogen, which, when mixed with acid, produces an enzyme, or ferment, known as *rennin.* This ferment has the power to coagulate milk, forming casein. Rennin is found wherever pepsin is manufactured, although distinctly different in character and action.

The fluid is not poured out at the same rate from the beginning to the end of digestion. The Mett method of preparing the proteid is to fill a glass tube, one to two millimeters in diameter, with egg-albumin and coagulate it at 95° C. The tube is then cut into small pieces and placed in 1 or 2 cubic centimeters of the juice to be investigated. The law of Schuetz is as follows: the quantity of pepsin in the compared liquids is proportionate to the square of the rapidity of digestion; that is, the square of the column of proteid in a Mett tube expressed in millimeters which the juices are capable of digesting in the same period of time. If one of the fluids digest a column of 2 millimeters of proteid and the other a column of 3 millimeters, the relative quantity of pepsin in each is not expressed by the figures 2 and 3, respectively, but by the squares of them; that is, 4 and 9; so that the second liquid is two and one-fourth times stronger than the first.

Not only the quantity of the secretion varies, but the secretion varies in composition with a greater or less quantity of ferment. Other properties of the juice are likewise varied. In one and the same juice the different ferments may suffer variations, running courses independently of each other, a fact which undoubtedly shows that the pancreas, which has a complex chemical activity, is able to furnish, during given periods of its secretory work, now one product and now another. That which may be said of the ferments may also be applied to the quantities of the salts in the juices. The gastric juice always has the same acidity as poured out by the glands, but on leaving the glands and running over the walls of the stomach, the mucus can neutralize 25 per cent. of it. The food also neutralizes the acid.

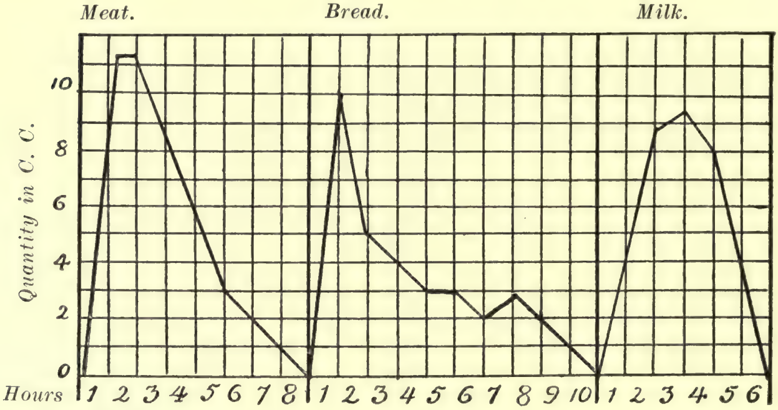

Fig. 16.—Hourly Variations of the Secretion of Gastric Juice in the Dog after a Meal of Meat, Bread, and Milk. (Pawlow.)

At the beginning of digestion, when the quantity of food is large and its external structure still coarse, the strongest juice should be poured out when most needed. The greatest digestive power belongs to the juice poured out on bread, which might, for brevity, be called "bread-juice"; the next strongest is "flesh-juice," and then comes "milk-juice." In other words, "bread-juice" contains four times as much ferment as "milk-juice." Not alone the digestive power, but likewise the total acidity, varies according to the nature of the diet. Comparing equivalent weight, flesh requires the most and milk the least gastric juice; but taking equivalents of nitrogen, bread needs the most and flesh the least. The hourly intensity of gland work is almost equal in the case of milk and flesh diets, but far less with bread. The bread, however, exceeds all others in the time required for its digestion, and the duration of the secretion is correspondingly protracted.

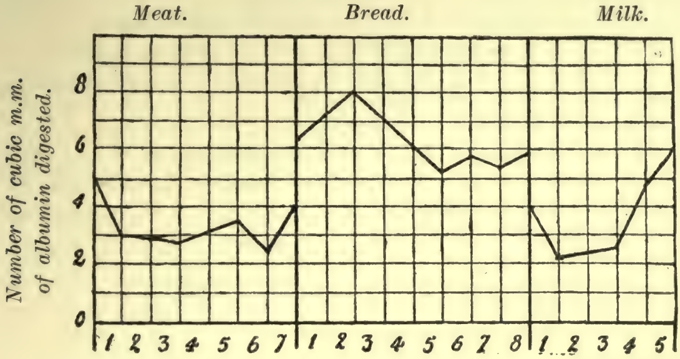

Fig. 17.—Hourly Variations of the Digestive Power of the Gastric Juice in the Dog after a Meal of Meat, Bread, and Milk. (Pawlow, Gley.)

Each separate kind of food corresponds to a definite hourly rate of secretion, and calls forth a characteristic alteration of the properties of the juice. Thus, with flesh diet, the maximum of secretion occurs during the first or second hour, and in both the quantity of juice furnished is approximately the same. With bread diet we have always a sharply indicated maximum in the first hour, and with milk a similar one during the second or third hour. On the other hand, the most active juice occurs with flesh in the first hour, with bread in the second and third hours, and with milk in the last hour of secretion. The point of maximum outflow as well as the whole curve of secretion is always characteristic for each diet. On proteid in the form of bread, five times more pepsin is poured out than on the same quantity of proteid in the form of milk, and the flesh-nitrogen requires 25 per cent. more pepsin than that of milk. These different kinds of proteid receive, therefore, quantities of ferment corresponding to the differences in their digestibility, which we already know from experiments in physiological chemistry.

Excitants of Flow of Gastric Juice.

Before the dog adapted for sham feeding, Pawlow cut up meat and sausage, when he obtained a great flow of gastric juice, more so than when he fed the dog with them; they escaped by the œsophagus. Here is a psychic excitation of the gastric secretion, which plays a considerable part in the production of gastric juice in the sham feeding experiment.

The appetite is, then, the first and mightiest exciter of the secretory nerves of the stomach. A good appetite in eating is equivalent from the outset to a vigorous secretion of the strongest gastric juice. Sham feeding of five minutes does not call forth a secretion for longer than three to four hours.

Mechanical excitation of the mucous membrane of the stomach does not cause the flow of gastric juice. Sodium bicarbonate in the stomach inhibits its secretion. Liebig's extract or meat-broth introduced into the stomach increases the secretion of gastric juice. Fat in the stomach inhibits the psychic secretory action of the stomach upon meat. The fat of milk can inhibit its digestion to a certain extent.

The secretory activity of the stomach depends on nervous processes. In the immense majority of cases gastric digestion begins by a strong central excitation of the secretory and trophic fibers of the glands.

Popielski has shown that a stomach with all nervous connections severed will secrete gastric juice, if extracts of meat are placed in the stomach. Edkins believes this secondary secretion of gastric juice to be due to the action of the products of digestion on the pyloric mucous membrane. They produce in the membrane a chemical substance, which is absorbed into the circulation, and, conveyed to the glands of the stomach, it acts as a specific excitant of their secretory activity. Starling calls it a gastric secretion or gastric hormone, similar to the secretin-exciting pancreatic secretion.

Secretory Nerves of the Stomach.

In a dog with a cannula in the stomach and the œsophagus opened so that food leaving the mouth goes through the opening in the œsophagus, and not into the stomach ("sham feeding"), the swallowing of food caused a great increase of flow of gastric juice. If, now, the pulmonary and abdominal vagi are divided on both sides, then sham feeding causes no flow of gastric juice. These experiments show that the gastric glands receive their normal impulses to activity by means of nerve-fibers in the vagi. Pawlow believes that secretory nerves of the stomach run in the vagi. Pawlow also excited the vagi after a previous section for some days and obtained an increase of gastric secretion. Atropine paralyzes the secretory nerves of the stomach. By the secretory fibers we mean those, according to Heidenheim, which stir up the secretion of water and inorganic salts of the gastric juice. The trophic fibers are concerned in the secretion of the ferment of the gastric juice. Sooner or later after the taking of food the influence of the reflex excitant comes into play, while the

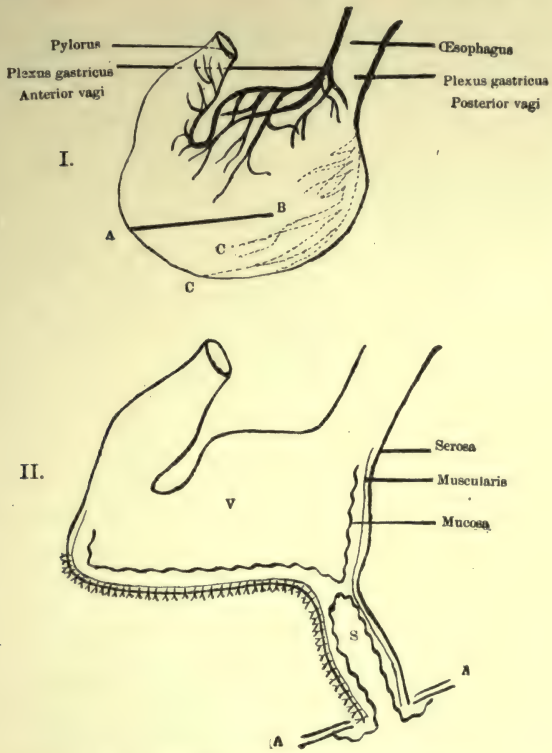
Pylorus
Plexus gastricus
Anterior vagi
Œsophagus
Plexus gastricus
Posterior vagi
I.
B
A
C
C
II.
V
Serosa
Muscularis
Mucosa
S
A
A

Fig. 18.—Dog's Stomach. (PAWLOW.)

I. *A-B*, Line of incision. *C*, Flap for forming stomach-pouch of Pawlow. II. *V*, Cavity of large stomach. *S*, Pawlow's pouch, or small stomach. *A*, *A*, Abdominal wall.

psychic effect dies out. If meat has been eaten, the secretory center will still be strongly excited in a reflex manner from the stomach and intestine, while, at the same time, the trophic center receives only weak impulses from the peripheral terminations of the nerves in question. When bread is eaten the reverse happens. After the cessation of the psychical stimulus, the secretory fibers are now only weakly excited through the end-apparatus; the trophic, on the other hand, are strongly influenced. In the case of fat foods reflex inhibitory impulses proceed to the centers which affect the activity of both secretory and trophic nerves.

ACTION OF AGENTS ON THE STOMACH.

When absolute alcohol or a strong emulsion of oil of mustard was introduced in the small stomach (Pawlow), there was an enormous secretion of mucus.

Ice-cold water in the large stomach (Pawlow) causes the secretion, which is subsequently produced by an ordinary meal, to be less than normal, more especially in the first hour; here is a special inhibitory reflex.

When alcohol is poured into the large stomach (Pawlow) an extremely free secretion of gastric juice begins in the small stomach (Pawlow). The secretion in the small stomach was compensatory for the arrested secretion in the large stomach.

In hypersecretion of the stomachs of dogs he found sodium bicarbonate to have a good effect. In hyposecretion he found water a good agent.

Borrisow has shown that bitter substances, such as gentian, excite the flow of gastric juice.

Hydrochloric acid, when secreted in considerable quantity, prevents further secretion of gastric juice. Phosphoric acid does not inhibit. Butyric acid strongly excites gastric secretion.

ACTION OF THE GASTRIC JUICE.

The amylolytic action of the saliva, the conversion of starch into maltose, is dependent upon the presence of ptyalin, an organic ferment whose action is best carried on in a neutral or alkaline medium. The proteolytic action of the gastric juice is due to the presence of *its* organic ferment, or enzyme,—pepsin,—in an acid medium. A partial digestion of certain foodstuffs can be accomplished in an acid solution, if given sufficient time and the proper temperature. There is, however, a strong tendency toward putrefaction during the process. On the other hand, pepsin alone is unable to perform any dissolution or digestion of the foods with which it comes into contact. But, if to it a 0.2-per-cent. solution of hydrochloric acid is added, proteolysis proceeds quickly and energetically. The powers of the gastric juice cannot be attributed to the presence, then, of its acid or pepsin alone, but to a combination which may be termed *pepsin-acid.* Thus gastric digestion is an acid digestion, and demands a knowledge of chemistry, for it is in many respects a chemical act. The result of the action of gastric juice on food is essentially the same whether the act takes place within the body or outside of it. Life has nothing to do with it, for it is a chemical action on the proteids of the food. In the stomach, then, the main process of digestion is the conversion of the proteids, through intermediate stages, into peptones, for pro-

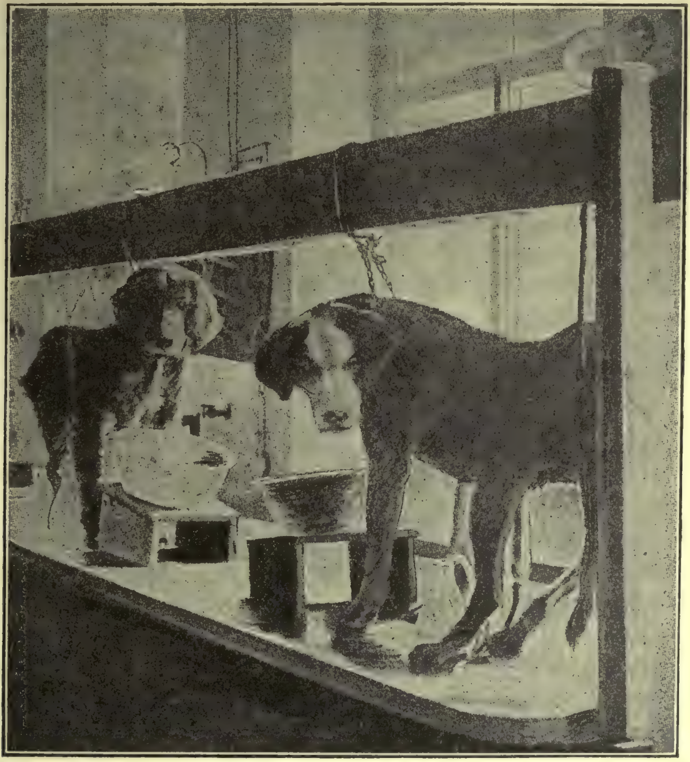

Fig. 19.—Dogs to whom a Fictitious Meal is Given. They have a fistula in the œsophagus and a fistula in the stomach. After a photograph taken in the laboratory of Pawlow. (Gley.)

teids are incapable of diffusion through animal membranes in the act of absorption.

Thus it can safely be stated that the prime and essential function of the gastric secretion is to dissolve the proteids present and convert them into peptones.

Gastric juice exercises no amylolytic influences upon any starch present; in fact, three-fourths of an hour after a meal, the action going on due to the saliva swallowed with the food is stopped altogether by reason of traces of free hydrochloric acid secreted by the oxyntic cells.

There is a fat-splitting ferment in the gastric juice of the fundus.

Those mineral matters which can be dissolved in hydrochloric acid of the strength of that found in the gastric juice are also dissolved in the stomach. The degree of solubility and efficiency attained by the gastric secretion far surpasses that of simple, diluted acid, probably because of the pepsin found in the former.

Although the amylolytic action of the saliva on starch takes place for a definite interval, the gelatinous envelopes of the fat-globules and mineral substances are dissolved within the receptacle of the stomach, yet the essential and characteristic feature of the work to be done there is on the proteids: converting them into peptone through the action of proteolysis.

The proteids found in Nature are very complex and as yet not thoroughly known. However much they, as individuals, may differ in composition, reactions, etc., yet they all possess an inherent tendency to undergo hydrolytic decomposition when conditions are favorable. Hydration and cleavage can be induced by simple heating in water alone raised to the temperature of 100° C., for there results partial solution of the proteids during the process. The proteolytic process of the gastric secretion in its converting proteids into peptones is also one of hydration and cleavage. The final products are not the result of one simple step, not the formation of one simple body or substance, as when the proteids are acted on by heated water alone. The acid in gastric digestion induces a row of chemical changes and products, each separate and distinct, and capable of being recognized by certain reagents.

By the action of *pepsin-acid* the proteid is first changed into (1) *syntonin,* or *acid-albumin.* By further action of the ferment, the acid-albumins are changed into (2) *proteoses,* with their divisions into *primary* and *secondary proteose.* The proteoses are the intermediate products between acid-albumins and peptones. These are found under various names in this group; as, the proteoses may be derived from albumin, when they are called albumoses; or from globulin, when the name globuloses is used. The proteoses are soluble in warm water, acids, and the alkalies. They are only slightly diffusible and not coagulated by the action of heat. Nitric acid produces a white precipitate, which is colored yellow by heat and dissolved again. When *cool,* the precipitate occurs again; this recurrence of the precipitate upon cooling is a distinctive feature of proteoses. Ammonium sulphate precipitates proteoses and leaves the peptones in solution.

By the continued proteolytic action of the gastric juice, the proteoses are changed into (3) *peptones,* the final, diffusible products of gastric digestion. They are simply the result of a process of hydration.

The peptones are very diffusible, particularly in acid solution. The utility and benefit to be derived from that characteristic is very evident when we keep in mind the chief aim of digestion, which is to render foodstuffs into soluble conditions so that they may be readily absorbed and so become a component of the blood and eventually of the tissues.

The peptones are soluble in water, but not precipitated from their aqueous solutions by the addition of acids or alkalies, or by boiling. In fact, peptones are never coagulated by heat. They are not precipitated by nitric acid, copper sulphate, ammonium sulphate. and a number of other reagents usually held as precipitants of proteids.

To differentiate albumoses from peptones, add a few drops of salicyl-sulphonic acid to several cubic centimeters of the original fluid. A white precipitate may indicate native proteid or proteoses. Boil, then the proteoses dissolve, whereas the native proteid becomes coagulated. Filter hot. If a precipitate forms in the filtrate on cooling, it indicates proteoses. Filter off this precipitate and apply the biuret test to filtrate. A rose-pink coloration indicates peptone.

However, the chief and striking feature of peptones is their great diffusibility. Other forms of proteid matter pass through animal membranes with very great difficulty, if at all.

When the proteids have been reduced to peptones, they are ready for absorption into the blood through the capillary walls. However, proteoses, the intermediate products, although less diffusible than peptones, find their way, to some extent, also, through the capillary walls. Experiment has demonstrated that pure proteoses, or even peptones, introduced *directly* into the blood are more or less toxic, and the system behaves toward them as foreign bodies, striving to get rid of them as speedily as possible. From this it is evident that there must be some transformation in the *very act of diffusion through* the *capillary walls,* else the nutritious proteid matters are not used in constructive metamorphosis, but expelled as foreign matters. The agencies which act upon these proteoses and peptones, in some manner destroy their toxic tendencies and, probably, convert them into the serum-albumin, or globulin, of the blood. The fact that peptones are not found in the blood and lymph during or directly after digestion confirms this idea, since peptones are absorbed as soon as manufactured. An excess of peptone in the stomach-contents would have the power to arrest proteolysis by its mere presence. A preparation on the market is somatose, a mixture of albumoses produced by the action of a ferment on meat. It is a predigested beef, and readily absorbed. It dispenses with the large amount of fluid which is necessary in peptonized milk.

Weinland has shown that the epithelium of the stomach and of the intestines forms antipepsin and antitrypsin, which prevent digestion of the stomach itself or of the intestine, by the ferments, pepsin and trypsin.

Antiseptic Action of the Hydrochloric Acid in Gastric Juice.

Besides the function which hydrochloric acid exercises as a component of the gastric secretion,—namely: of rendering the pepsin in it active,—it possesses another very powerful property as a *disinfectant* and *germicide* in that it can kill many bacteria that are taken in with the food. By means of it the bacteria producing putrefaction are killed, and thus disorders in the entire constitution as a result of abnormal digestion are prevented. Even when putrefaction has occurred in the food previous to its entrance into the stomach, upon reaching this receptacle it is stopped.

Many pathological bacteria are likewise destroyed by the acid in the juice, although some, as the bacillus of tuberculosis and that of splenic fever, are unaffected. It is interesting to note that experiment has shown that just about the amount and strength of hydrochloric acid as that in the stomach is needed *outside* the body to accomplish the death of putrefactive and many pathological germs. Acetic and lactic fermentations are arrested by mere traces of hydrochloric acid.

To epitomize: The general action of gastric juice is to convert the proteids into peptones by various stages. The fats are split up by a gastric lipase. Starch is unaffected.

The general result is the formation of a souplike mass in the stomach. This undigested food is passed through the pylorus into the duodenum of the small intestine, and is called chyme. The average time that food remains in the stomach is about three hours.

Günzburg's Test for Hydrochloric Acid.—With a solution of phloroglucin and vanillin in alcohol mix a drop of a solution of hydrochloric acid, 0.2 per cent.; evaporate slowly in a porcelain capsule, when a red color will appear.

Uffelmann's Test for Lactic Acid.—Add a trace of solution of ferric chloride to a 1-per-cent. solution of carbolic acid. This amethyst-colored solution will change to canary yellow on the addition of lactic acid.

VOMITING.

Vomiting is a spasmodic rejection of food from the stomach, and is usually a sign of some malady. The ease with which animals vomit is dependent upon the conformation of the stomach, particularly with regard to the fundus, as well as the condition of its contents. Thus, a child vomits easily, since its fundus is not very well developed; with the adult the act is one of great difficulty.

When the person is conscious, vomiting is usually preceded by a sensation of nausea, during which the saliva flows very freely into the mouth. While the food is being swallowed considerable air enters the stomach, and later assists actual vomiting by helping to dilate the cardiac orifice. Before the real expulsion occurs, and during the efforts to accomplish the same, a very deep inspiration is taken just as in the act of coughing. Immediately the glottis closes, and the muscles of the abdomen commence to contract very actively. Instead of the glottis opening to permit an expiration, it remains tightly closed, thereby holding the diaphragm immovably fixed, and so furnishing an unresisting plane against which the stomach is pressed. Immediately preceding the pressure brought to bear upon the stomach by the contraction of the abdominal muscles, there occurs a shortening of the longitudinal fibers of the œsophagus, thereby bringing the cardiac orifice of the stomach nearer the diaphragm, to form a straight passageway for the vomit to the pharynx. The muscles of the sphincter at the cardiac orifice are rather suddenly dilated, forming a funnel-shaped opening at the beginning of escape, since the pylorus usually remains closed. By the abdominal contractions and slightly assisted by gastric movements also, some of the contents of the stomach is forced into the opening of the œsophagus, where its movement toward the pharynx and mouth is aided by contractions of the œsophageal circular fibers: the reverse of what occurs when a bolus of food is swallowed.

Thus there are two separate and distinct acts occurring during vomiting: (*a*) the dilating of the cardiac sphincter and (*b*) the expulsive movements of the abdominal muscles. The absence of either act is detrimental to the accomplishment of vomiting. The pyloric gate is usually closed during vomiting; so that little or no substances find their way into the duodenum. However, when the gall-bladder is very full, the movements of the surrounding organs force its contents into the duodenum and very frequently some of the bile finds its way into the stomach, from whence it passes out through the œsophagus, pharynx, and mouth in bilious vomiting,

That the expulsive impetus is mainly given by the contractions of the abdominal walls and not the gastric movements alone has been proved by experiment. The stomach of an animal was excised and replaced with a bladder filled with water and attached to the œsophagus by means of a rubber tube. When the wound was closed and an emetic injected, the contents of the bladder were immediately expelled through the mouth.

Vomiting is normally considered to be a *reflex* action, although in some instances vomiting may proceed at will or be acquired after some practice. The afferent nerves are principally the *fifth,* the *glosso-pharyngeal,* and the *vagus.* The center of vomiting is located in the *medulla oblongata.* The efferent impulses are conveyed by the *vagi* to the stomach, *phrenics* to the diaphragm, and various *spinal nerves* to the abdominal muscles. Thus vomiting may arise:—

1. From irritation of the stomach, as when this organ is too full.

2. From tickling the vault of the palate.

3. From intestinal irritation by worms.

4. From irritation of the uterine mucous membrane during the first three months of pregnancy.

5. The remembrance or sight of disgusting sights, or pathological disorders of the brain may cause it, which proves that the brain is united to a vomiting center.

6. The use of emetics, which do not all act alike.

Thus, some emetics, as copper sulphate, mustard, etc., produce emesis because of their irritating effects upon the peripheral nerves in the mucous membrane lining the stomach. Others, like tartar emetic, apomorphine, etc., attain the same results by reason of their stimulating the vomiting center in the medulla.

DIGESTION IN THE INTESTINES.

When the food is converted into chyme and partially dissolved by the gastric juice, it passes into the small intestine, where it is subjected to new reagents: the bile, pancreatic juice, and intestinal juices. Here the food is prepared for absorption, forming what is called *chyle,* which is rapidly taken up by the chyliferous vessels.

Because of the small and large calibers of the two parts of the intestinal tract, the portions have received the names of *small* and *large intestines,* respectively. The small intestine, the continuation of the stomach, opens into the large intestine by an orifice which is guarded by the *ileo-cæcal* valve. Under ordinary and normal conditions this valve allows the passage of the remnants of active digestion to pass through from the small into the large intestine; very rarely does the reverse occur, except in some cases of hernia and other obstructions in the large intestine.

THE SMALL INTESTINE.

This tube is cylindrical and much convoluted. It occupies the umbilical region and is suspended from the vertebral column by the mesentery. It measures about twenty-five feet in length, and its diameter is about one and three-fourths inches. As it continues to join the large intestine it becomes slightly narrower. It consists of three parts: the duodenum, jejunum, and ileum.

The duodenum is twelve fingers' breadth in length, and it is the widest part of the small intestine. It commences at the pyloric end of the stomach and opposite the second lumbar vertebra; it terminates in the jejunum. The common bile-duct and the pancreatic duct perforate the inner side of the duodenum.

The jejunum constitutes about two-fifths of the small intestine. It is wider than the ileum and is characterized by the absence of the agminated glands. The ileum constitutes three-fifths of the small intestine, and terminates in the right iliac region by joining the large intestine at a right angle.

Structure of the Small Intestine.

Like the stomach, the intestine has four coats: (1) the external serous, (2) the muscular, (3) the submucous, and (4) the mucous coat. The serous coat is furnished by the peritoneum. The muscular coat is composed of two layers of pale, unstriped fibers, the external layer of longitudinal fibers, and the internal layer of circular fibers. The submucous coat is thinner than that in the stomach, but is also extensible.

The mucous coat is thinner and redder than that of the stomach, and, like it, has a columnar epithelium. It has folds of mucous and submucous tissue, running in a transverse direction and in the shape of a crescent, which are called the valvulæ conniventes. These valvulæ are more abundant in the upper part of the small intestine, where they overlap the edges. As you go down the small intestine you find the number of the valvulæ gradually lessen, and in the ileum they disappear. These folds are permanent. The minute elevations called villi beset the mucous membrane of the small intestine and even the valvulæ conniventes. They give a velvety appearance to the surface of the small intestine. In the upper part of the small intestine the villi appear as fine folds, but farther down the intestine they appear as flattened, conical projections. The villi are $^1/_{40}$ inch in height, and in structure are appendages of the intestinal mucous membrane.

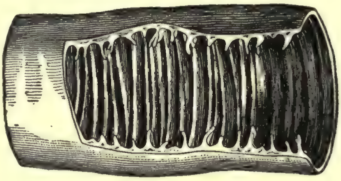

Fig. 20.—Portion of the Wall of the Small Intestine, Laid Open to Show the Valvulæ Conniventes. (Brinton, Raymond.)

Villi.*

Upon the surface of the villi you find an epithelium of regular cylindrical cells. The border cells of the epithelium of the villi have a broad, finely striated border which spreads over their ends like a cuticle or mosaic. The other end of the cell often ends in a point and is separated from the underlying tissues by a thin basal membrane. Each cell consists of a granular protoplasm containing an oval, well-defined nucleus lying in its lower half, in which a distinct nucleolus appears. The epithelial cells are joined together in bridges of a protoplasmic nature, with spaces between the bridges filled with cement substance. In cholera and in poisoning by arsenic these cells are shed. Between the epithelial cells roundish structures, either single or in small groups, and of a diameter greater than the epithelial cells, appear. They are quite transparent, have no true cell-membrane, and only a thickened ectoplasm, which undergoes no mucoid change. These cells are goblet-shaped, full of protoplasm, containing a compressed nucleus. It is generally considered that these two kinds of cells, the cylindrical and the goblet, are separate in origin; that is, a young epithelial cell cannot become changed into a goblet cell. The goblet cells discharge mucin, which goes to form the mucus. Fasting, active digestion, and excessive doses of pilocarpin increase their number.

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* Szymonowics's Histology has been drawn upon in the description of the villi.

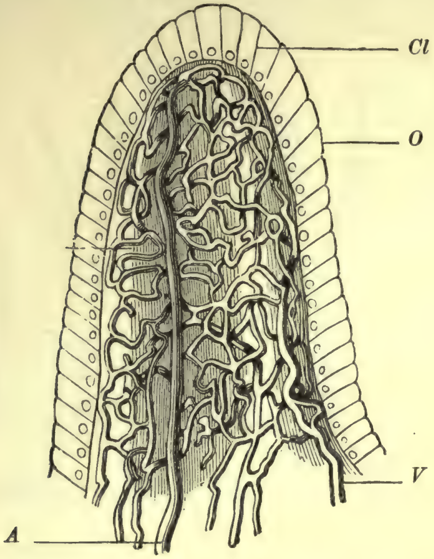

Fig. 21.—Blood-vessels of an Intestinal Villus. (Landois.)

Cn, Capillaries. *A*, Artery. *Cl*, Cylindrical epithelium. *O*, Surface of the epithelium. *V*, Vein.

Going inward from these cells we meet in the villus a basement membrane, immediately beneath it the blood-vessels, then the fibers of the muscularis mucosa and a single lacteal or lymphatic vessel. The body of the villus is composed of adenoid tissue, closely invested with small and numerous bundles of smooth muscular fibers arranged in a longitudinal and in an oblique direction, and derived from the muscularis mucosa. The longitudinal fibers, when they contract, shorten the villus and with the valves in the lacteal empty it, whilst the oblique fibers keep the lacteal open. These muscular fibers are attached to the sub-epithelial basal membrane. The lymph-spaces in the adenoid tissue form a network of channels communicating with each other, and contain leucocytes and fine globules of fat, which have passed through the spaces between the epithelial cells on the border, then through the basal membrane, through the lymph-spaces of the parenchyma of the villus, and finally enter the lacteal. The lymph-vessels end in the upper part of the villus, in a blind extremity, and show a certain degree of anastomosis, and when joined form the central chyle-vessel or lacteal. The lacteal lies in the center of the villus, whilst the artery enters to one side of it and spreads out into a network of capillaries, like an umbrella, over the lacteal immediately underneath the epithelium of the villus. The number of the villi has been estimated to be about four millions.

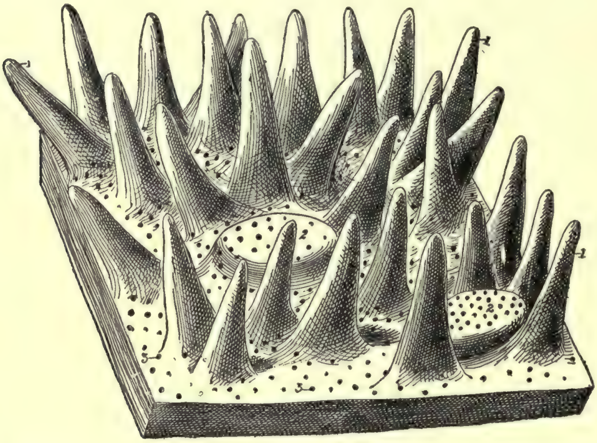

Fig. 22.—Mucous Membrane of the Jejunum, Highly Magnified. (schematic). (Testut, Raymond.)

1, 1, Intestinal villi. 2, 2, Closed or solitary follicles. 3, 3, Orifices of the follicles of Lieberkühn.

Glands of the Small Intestine.

There are four kinds of glands in the mucous membrane of the small intestine. They are: duodenal, or Brunner's; glands of Lieberkühn; solitary; and agminated glands, or Peyer's patches.

Brunner's glands are small, racemose glands situated in the submucous tissue of the duodenum. Toward the end of the duodenum they gradually disappear.

The glands of Lieberkühn are the most numerous of all the glands of the small intestine, and they exist from the pyloric end to the ileo-cæcal valve. They are placed in a vertical direction in the thickness of the mucous membrane and open between the villi. They are about $^1/_{100}$ inch in length. They have thin walls lined with a columnar epithelium.

The solitary glands are found in all parts of the mucous membrane of the small intestine. They are minute, whitish, oval or rounded bodies scattered singly in the intestine. They are closed vesicles, and are situated in the submucous tissue. They are lymph-nodules composed of retiform tissue and lymphocytes.

The agminated glands (Peyer's) are formed of solitary glands, disposed in oval patches. Usually there are fifteen to thirty of these patches, from one-half to two inches in length, and one-half inch in breadth. The ileum is their usual habitat, and they are seated opposite the attachment of the mesentery. In the neighborhood of the ileo-cæcal valve they are larger and more numerous. As the duodenum is approached they are smaller and fewer. In youth they are distinct, less so in adult life, and in old age may disappear. They are the seat of ulceration in typhoid fever. The arteries of the small intestine are the superior mesenteric and pyloric. The lymphatics are numerous. The nerves are given off by the solar plexus. Beneath the mucous coat in the areolar tissue of the small intestine are Meissner's ganglia. Between the muscular coats the ganglia of Auerbach can be found.

THE LARGE INTESTINE.

This is a cylindrical tube differing from the small intestine in having a greater capacity and a sacculated appearance. It is about five feet in length and extends from the ileo-cæcal valve to the anus. It nearly encircles the abdomen in its course. Like the small intestine, it is divided into three parts: the cæcum, colon, and rectum. The head of the colon, the cæcum, is a wide, blind pouch, or *cul-de-*

sac, about two and one-half inches in length and breadth. Toward its bottom it curves inwardly and backward and is abruptly reduced to a wormlike prolongation—the vermiform appendix. The small intestine opens into the cæcum, the orifice being guarded by the ileo-cæcal valve. The second and largest part of the large intestine is the colon, and it extends from the cæcum to the rectum. It consists of four parts: the ascending, transverse, and descending colon, with the sigmoid flexure. Its diameter is greatest at its commencement, being about two and one-half inches; but it gradually lessens to an inch. The sigmoid flexure is shaped like the letter S. It is the narrowest part of the colon. The rectum extends from the sigmoid flexure to the anus. It is about seven inches in length. When distended the rectum is club-shaped, being narrow above and expanded just before it contracts to the anus. The anus is completely surrounded by a sphincter muscle.

Structure of the Large Intestine.

The cæcum and colon, like the small intestine, have four coats: the (1) serous, (2) muscular, (3) submucous, and (4) mucous. The mucous membrane contains two kinds of glands: the glands of Lieberkühn and the solitary glands. The glands of Lieberkühn are closely set together and give a peculiar sievelike appearance to the surface of the mucous membrane.

Experiments upon the cæcum of the cadaver prove that the action of the ileo-cæcal valve is not dependent upon muscular contraction, for fluid forced through the large intestine rarely passes into the ileum. When the cæcum is filled the dilatation of the same presses upon the folds of the valve so as to press them tightly together and thus prevent any reflux into the small intestine.

MOVEMENTS OF THE INTESTINES.

As was the case with the œsophagus, the intestines are composed of two muscular coats: an outer longitudinal one and an inner circular one. Movements in them are caused by alternate contractions and relaxations of adjoining portions of the tube. To the characteristic movements of the intestines two names have been given to describe two separate forms: (1) *peristaltic* and (2) *pendular.*

Peristalsis.—By this term is implied the alternate contractions and dilatations of adjoining segments to produce a wavelike motion which proceeds from its point of origin anywhere along the intestinal tract *away from* the stomach. "Antiperistalsis" is the term used to designate the movements running in an exactly opposite direction: that is, *toward* the stomach.

Pendular Movements.—These are the very slight swinging to-and-fro oscillations, probably caused by the contractions of the longitudinal fibers.

Cannon has shown that in the cat, when fed, a portion of the small intestine may be seen, with its continuous contents, to suddenly be divided into segments. These segments are then also subdivided. This segmentation of the intestinal contents does not move the food along. A peristaltic wave does that. These movements incorporate the food with the ferments. When a peristaltic wave reaches the ileo-colic sphincter, it relaxes and permits the intestinal contents to pass into the colon. If a reflux wave of the colon takes place, it contracts, when the proximal part of the colon is distended. Then contractions, an antiperistaltic wave, travel from the point of union of the ascending and transverse colon towards the cæcum. Then peristaltic waves drive the contents into the distal colon.

In the large intestine, the distal part of the colon and its adjacent sigmoid flexure are a resting place for the fæces, and are concerned in defecation. The chief point about the distal colon is its complete subordination to the spinal cord. The ileo-colon, the transverse colon, and the descending colon are a place for the propulsive peristalsis, as the descending colon is never distended.

NERVE-SUPPLY OF THE INTESTINES.

The small intestine receives fibers from the greater and smaller splanchnic nerves, which pass through the semilunar and superior mesenteric ganglia, and then pass along the mesenteric arteries to their destination. The right vagus also supplies the intestine with fibers.

The sympathetic ganglia of Auerbach lie between the two muscular coats and extend from the œsophagus down throughout the small and large intestine. Meissner's ganglia, also belonging to the sympathetic system, lie in the submucous coat. The vagi convey motor impulses to the intestine, while the sympathetics mainly convey inhibitory, although they also carry motor, impulses. Slight stimulation of the splanchnic calls out motion, strong stimulation inhibition of the intestinal movements. I have found that, when the right vagus is divided in a rabbit and the cardio-inhibitory fibers are allowed to degenerate for five days, electric stimulation of the cut vagus slows the pendular movement.

Stimulation of any portion of the intestine causes contraction above the place of irritation, and inhibition or relaxation below the point of irritation. This causes the food to move onward, and is due to Auerbach's plexus. This is the "*law of the intestines,*" according to Bayliss and Starling.

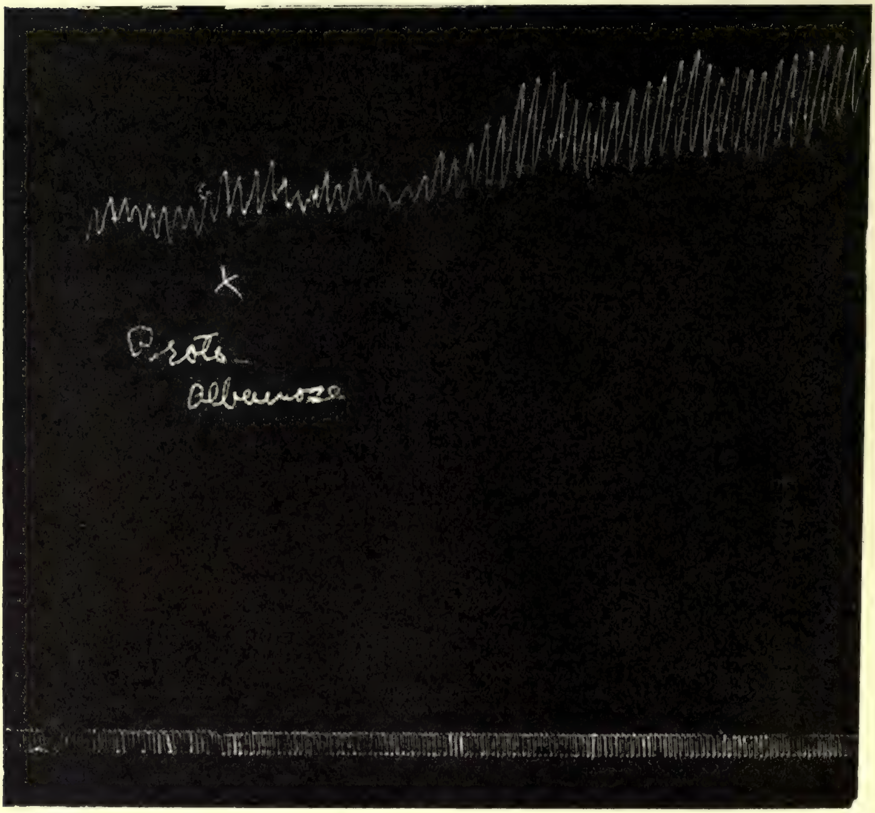

Fig. 23.—Effect of Albumose, increasing Peristalsis.

The descending colon has its nerve-supply from two sources: (1) fibers from lumbar nerves to sympathetic chain and mesenteric ganglia, and from the mesenteric ganglia, by fibers running in the hypogastric nerves and plexus; (2) fibers from sacral nerves, running in the nervi erigentes and entering the pelvic plexuses, which are motor and antagonize the preceding fibers, which are inhibitory. When the small or large intestine is excised, it has peristaltic movements, which are due to Auerbach's plexus acting as a reflex center.

I have found that albumoses and peptones increase peristalsis. This has been confirmed by Roger. Atropin increases the peristaltic movements, probably by an action on the post-ganglionic fibers. Langley believes that nicotine and curare, in intestinal peristalsis, act on a substance intervening between the nerve-ends and the muscle, a myoneural substance.

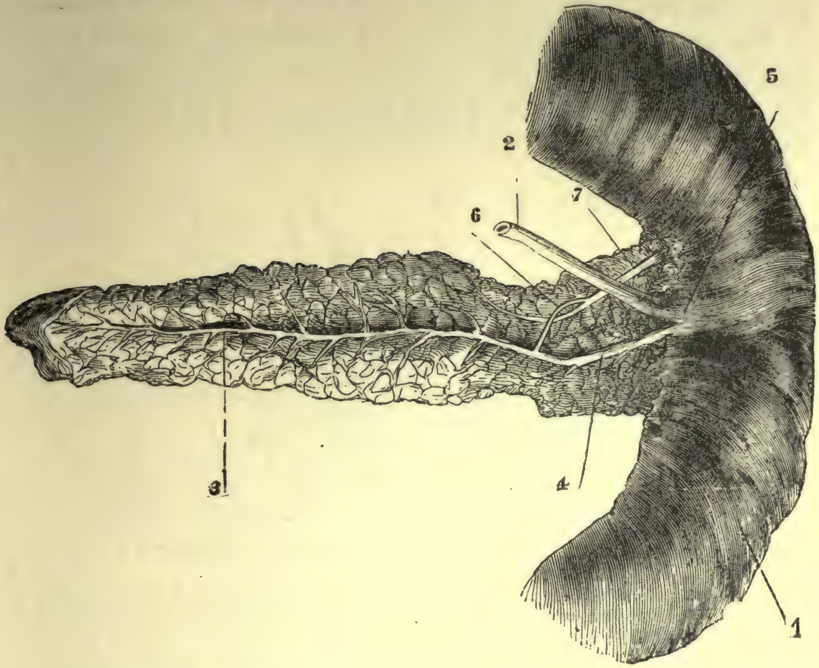

Fig. 24.—The Pancreas. (Posterior View.) (BOURGERY.)

1, Duodenum. 2, Duct. choledicus. 3, Duct of Wirsung. 5, Union of the two ducts. 7, Accessory duct.

The distension of the abdomen, in many diseases of this region, is probably due to a reflex inhibition by the way of the splanchnic nerve, which has power over the tonus of the caliber of the intestine.

Salines are supposed to act as aperients by their presence in the blood, causing an increased secretion to be poured out by the blood-vessels into the intestinal canal. The theory of endosmosis has been abandoned.

PANCREAS.

The pancreas is a long gland, of a reddish-cream color, and is situated behind the stomach. Its pointlike extremity comes in contact with the spleen. It closely adheres to the duodenum. It is about seven inches in length, its width about one and one-half inches, and its thickness about one-half inch. The right and large end is the head; its left free end is its tail. The duct of Wirsung, or the pancreatic duct, the size of a goose-quill, runs the entire length of the gland. Upon leaving the pancreas the duct penetrates the wall of the duodenum, opening in conjunction with the common biliary duct, about three inches from the pylorus.

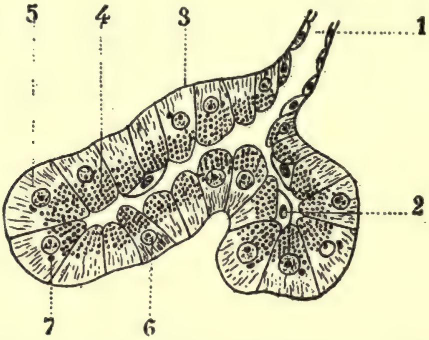

Fig. 25.—Schematic Section of Pancreas. (Vialleton.)

1, Origin of excretory canal. 2, Centro-acinar cell. 3, Pancreatic cell. 4, Granular internal zone, zymogen granules. 5, External zone, clear part of cell. 6, Nucleus. 7, Accessory nucleus.

Structure.

In structure the pancreas is an acino-tubular gland, resembling the salivary glands. In fact, it has very frequently been called the abdominal salivary gland. The lobes are composed of ducts which have been convoluted, terminating in alveoli or sacs and which unite with other tubules so as to communicate with the main duct. The small ducts are lined with short columnar epithelial cells which are smaller than those of the salivary glands. The secretory cells of the pancreas are large and rounded, being distinctive in that they possess an outer portion which is nearly or quite homogeneous, staining readily with dyes, and an inner portion, very granular, which does not stain easily. The latter forms about two-thirds of the cell. When the gland is inactive the cells are heavily charged with granules and the lumen is almost invisible. When active, the cells first swell up and press outward against the basement membrane: later they diminish in size as the granules pass out through the now opened lumen, and so leave a large, clear zone. The presence of these numerous small granules marks the presence, in the cells, of a zymogen, termed *trypsinogen*, which is the precursor of trypsin, the active ferment of the pancreatic juice. In the interalveolar tissue are islets of small cells permeated with a close network of convoluted capillaries. These cells are also met with in the carotid and coccygeal glands. In the pancreas they are called cells of Langerhans, and are often degenerated in pancreatic diabetes.

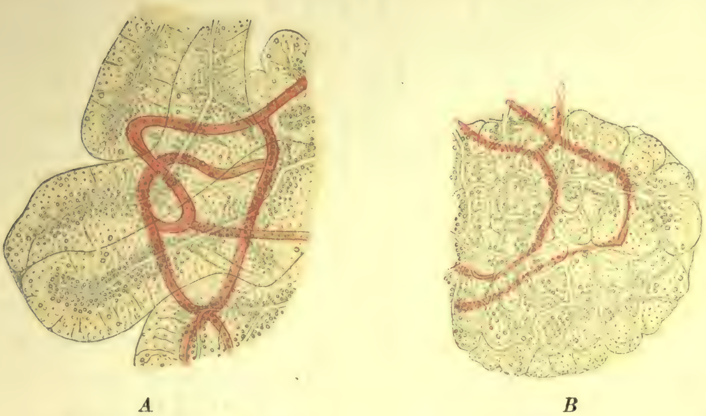

Fig. 26.—Pancreas of Rabbit Observed During Life. (Kühne and Lea.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

***A*, Resting gland. *B*, Secreting gland.**

The pancreatic blood-vessels are derived from the *splenic* and branches of the *hepatic* and *superior mesenteric*. Its nervous supply comprises networks of fibers from the *splenic plexus.*

Pancreatic Secretion (Pawlow).

Each kind of food determines the secretion of a definite quantity of pancreatic juice, while the result as regards ferments is truly striking. The greatest amount of proteid ferment is found in "milk-juice," less in "bread-juice" and "flesh-juice." The most amylolytic ferment occurs in "bread-juice," less in "milk-juice" and "flesh-juice." On the other hand, "bread-juice" is extraordinarily poor in fat-splitting ferment; "milk-juice," on the contrary, is very rich, "flesh-juice" taking an intermediate position. It is clear that as regards the two latter ferments the properties of the juice correspond with the requirements of the food. The starch-holding diet receives a juice rich in amylolytic ferment, the fat a juice rich in fat-splitting ferment.

The behavior of the proteid ferment may puzzle the student. In the work of the gastric glands we saw the weakest, here in the pancreatic juice the strongest, ferment poured out on milk. When, however, we take the quantity of juice into consideration we find here also that administration of like quantities of proteid in the form of bread, flesh, and milk calls forth a secretion as regards the first of 1978, as regards the second of 1502, and as regards the third of 1085 ferment units; that is to say, vegetable proteid likewise demands from the pancreas the most, milk and milk proteid the least, ferment. The difference between the stomach and the pancreas is limited to this: that the former pours out its ferment in very concentrated form upon bread, the latter in a very dilute condition. This fact strengthens the supposition that in the digestion of bread a large accumulation of hydrochloric acid has to be avoided.

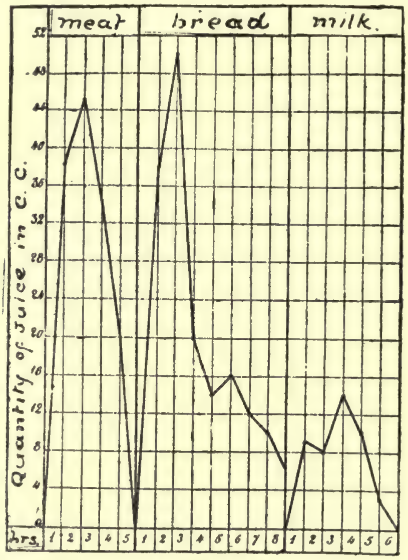

Fig. 27.—Hourly Variations of the Pancreatic Secretion after a Meal of Meat, Bread, and Milk. (After a curve obtained in the laboratory of Pawlow by one of his pupils, A. Walther.)

When in feeding animals the kind of food is altered and the new diet maintained for a length of time, it is found that the ferment-content of the juice becomes from day to day more and more adapted to the requirements of the food. If, for example, a dog has been fed for weeks on nothing but milk and bread and is then put on an exclusive flesh diet, which contains more proteid, but scarcely any carbohydrate, a continuous increase of the proteid ferment in the juice is to be observed. The capability of digesting proteid waxes from day to day, while, on the contrary, the amylolytic power of the juice continuously wanes.

When under the influence of a given diet this or that condition of the pancreas had been established in experiment-animals in characteristic form, Pawlow was able, by altering the feeding, to reverse it several times in the same animal. It seems then that the gastric and pancreatic glands have what may be called a form of instinct. They pour out their juice in a manner which exactly corresponds both qualitatively and quantitatively to the amount and kind of food partaken of. Besides, they secrete precisely that quantity of fluid which is most advantageous for the digestion of the meal.

Hydrochloric acid of gastric juice acts on pro-secretin in the epithelium of duodenal mucous membrane, producing *secretin,* a hormone[1] which, when absorbed, greatly excites pancreatic secretion. Fats in the stomach retard stomachic secretion, but increase pancreatic secretion, chiefly by a reflex action through the duodenum, and not from the mucous membrane of the stomach. Sleep does not arrest pancreatic secretion.

Psychical effect, strong craving for food and water, are common excitants for both gastric and pancreatic secretion. The extractives of meat excite the gastric secretion, while acids and fats excite the pancreas.

Sodium bicarbonate and alkalies inhibit pancreatic secretion.

Secretory Nerves of Pancreas.

In nonnarcotized dogs whose vagus was divided four days previously and whose cardio-inhibitory fibers had lost their irritability, Pawlow irritated the vagus without pain and obtained an increased pancreatic secretion. He found that vasoconstriction of the pancreatic vessels prevented the action of the vagus on the pancreas, as did compression of the aorta and pain. He also found in the vagus inhibitory fibers of the secretion, as well as secretory. He believes that secretory fibers also run in the sympathetic, not only for the pancreas, but also for the stomach.

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[1] Hormone is derived from a Greek word, meaning to excite.

The usual method of obtaining pancreatic juice for experimental purposes is by insertion of a cannula or by a fistula into the duct of Wirsung. By this method practically normal secretion is procured, whose composition is variable at different times, depending upon whether the fluid is collected three or four hours, or two or three days, after the operation. The secretion examined shortly after the operation is meager in quantity, though rich in solids; that collected a day or two later is more copious, but contains a smaller proportion of solid constituents. This is probably due to inflammatory changes in the pancreas as a result of the operation. The pancreatic juice examined is usually obtained from dogs, human secretions of the gland having been but rarely analyzed, and it has never been obtained under quite normal conditions. Most experiments are performed with the aid of an artificial juice made by mixing a weak solution (1 per cent. sodium carbonate) with a glycerin extract of pancreas. It is usual to treat the pancreas with a dilute acid several hours previous to its being mixed with glycerin to convert the zymogen, or mother-substance, trypsinogen, into the ferment, trypsin.

Normally, the pancreatic juice is colorless, viscid, and gummy; it flows in large, pearl-like drops, which become foamy on agitation. The fluid is without odor, and gives to the tongue an impression of a viscid liquid and a taste like that of salt. The reaction is always alkaline; its specific gravity about 1.030.

In consequence of the removal of a pancreatic tumor Zawadski obtained human pancreatic juice through the fistula remaining, which possessed powerful digestive properties, and found it to be made up of the following composition in a thousand parts: 135.9 parts were of solid nature, the remaining ones being water. Of the solid portions, 92 were proteids, 3.4 parts were inorganic in nature, while the remainder were organic substances soluble in alcohol. The figures repsenting the quantities of secretion in twenty-four hours are very various as given by different observers, but it has been roughly estimated to average about 1 pound.

The flow of pancreatic juice is somewhat as follows: Before the meal is finished there begins the secretion, which reaches its maximum point at about the third hour. After this the secretion sinks till about the sixth or seventh hour, when it increases to the ninth or eleventh hour, only to sink gradually to the eighteenth or twentieth. When the quantity is greatest the quality is poorest, and *vice versa.* Thus the function of the pancreas in man is intermittent. During secretion the gland is very red, and its vessels dilated, and the venous blood red. During repose the gland is flat and of a pale-yellow color, while its blood-vessels are contracted. The secretion is probably caused by secretin and the reflex action due to the contact of the foods. The pancreatic secretion can be moderated or suppressed equally by reflex action, notably in vomiting.

Of the 3.4 parts of an inorganic nature, the most abundant is sodium chloride, with alkaline and earthy phosphates and alkaline carbonates. The alkalinity of the juice is due principally to the phosphates of sodium. Pilocarpine increases the secretion, while atropine diminishes it.

The *organic matters* of the pancreatic juice comprise *four* principal enzymes or ferments. They are: (1) *trypsin,* (2) *amylopsin,* (3) *steapsin,* and (4) a *milk-curdling ferment.*

Trypsin, a very important constituent of the pancreatic secretion, is much like pepsin of the gastric juice, in that it is a proteolytic enzyme acting on the proteids and transforming them into peptones through intermediate stages. However, its fermentative powers are much stronger and its range of activity extends over more space than do those of pepsin. Atlhough pepsin and trypsin possess many properties in common, yet they are distinctly different and separate bodies. The main, characteristic difference is that pepsin requires an acid medium for its activity, while trypsin acts and performs its functions best in an alkaline solution whose strength ranges from 0.5 to 1 per cent. Experiment has proved that trypsin *can* act in a neutral or *very slightly* acid medium.

A remarkable feature of trypsin is the large and rapid transformation of proteid matter of any kind into peptone. This it produces when in only a moderately strong solution. Thus, it is a very capable body to take up the work of proteolysis where the pepsin of the gastric juice left it. since it is particularly a peptone-forming ferment. As the final products of proteolysis, there result *peptones.* When these come into contact with the pancreatic juice, they are quickly broken down into simple, crystalline bodies, as *leucin, tyrosin, aspartic acid,* arginin, and a polypeptid.

Like pepsin, the proteolytic action of trypsin is one of contact also, only it displays its powers more remarkably and energetically, in that it needs no environing bodies to set it in action other than water, the proteid matters, and temperature equal to that of the body. Trypsin displays no digestive powers on nuclein, keratin, or starches. There are vegetable trypsins like papain of Carica papaya, and bromelin of pineapple juice.

Hydrochloric acid quickly destroys trypsin unless there is great excess of proteid substances present, which means that the acid is combined with them and rendered less active. When a filled pancreas-cell is examined, the little granules within are found not to be active trypsin, but the precursor, or mother of the ferment. This zymogen, *trypsinogen,* is readily converted into the ferment by the presence of a trace of acid, since a great quantity will immediately kill the newly formed ferment as soon as generated.

Amylopsin,—This starch-splitting ferment converts starch partly into dextrin, but chiefly into isomaltose and maltose. During the first month of life it is thought that no amylopsin is formed; hence children of that age should not be fed starches. Amylopsin differs from ptyalin in that it can digest cellulose, so that it is capable of acting on unboiled starch. In many cases the failure of digestion of the carbohydrates by the amylopsin is associated with drowsiness after meals and slight headache.

The Steapsin, or Fat-splitting Ferment, decomposes the neutral fats into fatty acid and glycerin. It also emulsifies the fats: an activity which is assisted by the bile. One part of the fatty acids set free by the steapsin combines with alkalies in the intestine to form soap. This soap favors the emulsification of the fats. Another part of the fatty acid is absorbed as such and combines with glycerin in the intestinal wall again to form a fat. Kastle and Loevenhart have shown that lipase also has a reversible action: that is, it can make the fatty acids and glycerin reunite after they have been separated by it. The steapsin acts best in an alkaline medium, for acids stop it. Glycerin does not dissolve steapsin; so that a glycerin extract is not suitable for an experiment.

The Fourth Ferment present in the pancreatic juice is an unnamed one, which, like rennin, has the power to coagulate milk. It is hardly possible that its powers are exercised extensively, if at all, since the milk is probably coagulated in the stomach by the rennin found there before it ever reaches the duodenum. The so-called "peptonizing powders" are composed of pancreatin and sodium bicarbonate.

From the nature of the resulting precipitates in the transformation of the caseinogen into casein, it is evident that the two ferments —rennin of the stomach and that found in pancreatic juice—are markedly distinct and dare not be confounded. Rennin seems to require the presence of calcium salts before it can produce coagulation, which, when it does occur, presents the casein in the form of a coherent clot entangling in it the fats present. There is squeezed out, as it were, from the closely formed curd a clear, yellowish liquid, known as the whey, containing some proteids with the salts and sugar of the milk.

On the other hand, experimentation shows that the ferment in pancreatic juice does not require the presence of the calcium salts for precipitation of caseinogen; further, that the precipitate which does occur is very *finely granular* in nature; at the same time the milk seems to undergo no change in its fluidity, as far as can be distinguished by the naked eye. The presence of certain salts, which entirely check the action of rennin, but slightly hinder the action of the pancreatic ferment. It is believed that this pancreatic casein is not a true casein, for rennin placed in its presence has the power to change it still further, the resultant product being identical with true casein.

Effects Resulting Upon Removal of Pancreas.

It was in 1889 that von Mering and Minkowski by experiment upon the lower animals proved that removal of the pancreas was in every case followed by the appearance of dextrose in the urine, a condition known as diabetes, plus those symptoms marking the absence of pancreatic secretion in the intestinal canal during digestion. In the blood there was as much as 0.5 per cent., while in the urine the 8-per-cent. mark was reached. These investigators found that animals presented the identical characteristics as do human beings suffering from the same disease, namely: an abnormal excretion of water with the appearance in the urine of dextrose, acetone, and aceto-acetic acid. Another step was determining that this condition is not due to want of the pancreatic secretion in the intestine by tying the duct of Wirsung or else plugging it and its branches with paraffin, but allowing the organ to remain in its proper position in the body. The presence of a certain proportion of the whole gland, even though its secretion be not allowed to reach the intestines, will prevent diabetes; absence of this diseased condition is still maintained though a portion of the gland be removed from its normal position to be transplanted elsewhere.

From these data it would seem that the pancreas possesses virtues in the general economy other than merely producing pancreatic juice.

Any disturbance to these functions is felt not only in the gland itself, but throughout the entire body, since then its metabolism is disturbed. Thus is very clearly established one other instance showing the intimate relation that each and every organ or part bears to the general mechanism of the entire body as a unit, and the consequent general disturbances following its disease.

The transfusion of diabetic blood into a normal animal fails to produce within the recipient any diabetic symptoms. From this we learn that there was no accumulation in the blood of poisonous matter which the pancreas was supposed to remove. From the facts noted it is apparent that removal of the pancreas produces diabetes, not from any influence upon surrounding sympathetic ganglia or hindrance to passage of its secretions into the intestinal canal, but is caused by the removal from the system of something, which something possesses powers aside from those employed in digestion. The salivary glands, whose structure is similar to that of the pancreas, when removed give no untoward results. When the structures of these two glands are minutely and carefully examined, it is found that there is but one difference: in the parenchyma of the pancreas there are present little cells,—of Langerhans,—epithelial in appearance, richly supplied with blood-vessels, but having no connection with the alveoli or ducts of the gland.

Cohnheim found a body in the pancreas which he calls the activator, which resembles an internal secretion like adrenalin. When this activator is added to muscle-extract, it breaks up the sugar in the blood. Consequently the removal of the pancreas or its activator lets the sugar appear in the urine. Seventy-five grams of muscle and about .08 gram of pancreas are the best proportions to destroy the greatest amount of glucose. The pancreatic activator is not injured by boiling, and is soluble in alcohol, which facts show that it is not a ferment. It is now believed that there is some internal secretion manufactured by these patches of Langerhans cells in the pancreas, which is a very powerful factor in the disintegration of carbohydrates, but whose removal allows the abnormal production in the blood and urine of dextrose. According to several observers, the islets of Langerhans are not independent structures of separate origin, but are formed by certain definite changes in the arrangements of the secreting cells of the pancreatic tissue. Secretin exhausts the pancreatic cells, and thus converts the greater part of the secreting tissue into islet tissue.

The embryological evidence furnished by Laguesse and Dale shows that pancreatic growth is a function of the islet-tissue cell, multiplication being observed only in the islet. As the islets are formed from the alveoli, there must be a constant disappearance of islets and a new formation of the alveoli.

In pancreatic diabetes the proportion of dextrose to nitrogen (D : N) excreted in starvation is 3 to 1. In this kind of diabetes, the sugar is derived from the glycogen; and when the glycogen is used up, it, like the nitrogen, comes from the proteid. In ordinary states, after the removal of the pancreas the sugar comes from the dextrose in the food, and from the proteid of the food and of the tissues. The cause of accumulation of sugar in hyperglycæmia is the removal from the organism of some influence necessary to oxidize the dextrose. Lævulose can still be oxidized and also form glycogen.

Continued Action of Trypsin.

The proteid molecule is more thoroughly broken up by trypsin when it has been previously acted upon by pepsin, than when attacked by trypsin alone. When the action of trypsin is continued for a long time, it acts like an acid, hydrolyzing the proteid product and forming mainly amino-acids, that is, organic acids containing one or more amido groups in direct union with carbon. The amido-acids are chiefly as follows:—

1. MONO-AMINO ACIDS.—Glycocoll, alanin or amino-propionic acid, phenylalanin, amino-butyric acid, and leucin, which crystallizes in the form of spheroidal crystals.

Leucin ($C_6H_{13}NO_2$) is an a-amido-isobutylacetic acid, belonging to the fatty acid series. It is always formed in any profound decomposition of proteid, such as boiling with dilute acids, or alkalies, in tryptic digestion, or putrefaction. It has been found in nearly every tissue of the body in some proportion, being particularly common in pathological conditions of the tissues. It may be produced synthetically in the chemical laboratory.

(*a*) *The mono-amins of dibasic acids:*—Aspartic acid, glutaminic acids.

2. THE DIAMINO ACIDS.—The so-called hexone bases, arginin, lysin, histidin.

Arginin is a product of hydrolysis of all proteids, being the most abundant of the basic substances. It is especially found in the proteid of certain seeds and in the protamins. Salmin, a protamin of the spermatozoa of salmon, contains 80 per cent. of arginin. This is changed into urea in the liver by a ferment, arginase. Drechsel has estimated that about one-ninth of the urea excreted could arise from this source alone.

(*a*) *Other diamino acids:*—Diamino-glutaric acid, diamino-adipic acid.

3. HYDROX-AMINO ACIDS.—Serin, tyrosin, found also in elder-berries, in potatoes and germinating cucumbers.

Tyrosin ($C_9H_{11}NO_3$) belongs to the aromatic group, and is known as oxyphenyl-amido-propionic acid. It is a constant associate of leucin. It is from tyrosin, however, that cresol and phenol are formed.

4. A-PYRROLIDINCARBOXYLIC ACID, or prolin.

5. CASEANIC ACID.—Caseinic acid.

6. TRYPTOPHANE OR INDOL-AMINO-PROPIONIC ACID.—This crystalline body gives, on distillation, indol and skatol. When the amido bodies are formed from the proteid molecule by the trypsin, a nucleus of the proteid molecule remains, which is a polypeptid.

7. THE SULPHUR BODIES.—Albumin, when treated with lead salts in the presence of caustic alkali, yields a black coloration, indicating the presence of sulphur in the molecule. One of these bodies is cystin.

8. THE CARBOHYDRATE GROUP.—There are certain proteids. amongst which are mucins and cartilage, which readily yield a carbohydrate group on hydrolysis. Serum-albumin and egg-albumin contain a carbohydrate group which forms no small part of the whole molecule of albumin. Thus egg-albumin contains glycosamin—this last fact is important in the consideration of diabetes; the sugar comes from the proteid.

Glycosamin injected into the circulation is in great part eliminated as such. Proteids containing glycosamin are completely oxidized. One-twelfth of egg-albumin is glycosamin.

It has been shown by Giselt that alcohol, when given either by the stomach or rectum, increases the secretion of the pancreatic juice by an action through the vagi. The vagi contain the secretory nerves of the pancreas. However, alcohol reduces the digestive activity of the trypsin, the amylopsin, and the steapsin.

I have found that an infusion of the pancreas, when injected per jugular, decreases the pulse and the arterial tension; afterward the tension rises.

LIVER.

The largest gland in the body is the liver. Its shape is that of a triangular prism or ovoidal, with its long diameter transverse. Its convex surface is against the diaphragm. Its concave surface is in contact with the stomach, colon, and right kidney. The right and left lateral ligaments, with the suspensory ligament, hold it in position. It weighs from three to four pounds. The right portion of the liver is much larger than the left. It is also thicker and extends lower in the abdomen and higher in the thorax. It is of a firm structure, smooth on the surface, and of a reddish-brown color. The liver has five lobes, five fissures, five ligaments. and five vessels. The chief fissure to remember is the transverse fissure, which is the point where the blood-vessels and nerves enter the liver and where the lymphatics and excretory duct emerge. The lobes are the quadrate, caudate, right and left, and lobus Spigelii, the most important being the right and left. The vessels are the hepatic artery, vein, and duct, the portal vein. and lymphatics. The nerves are derived from the solar plexus

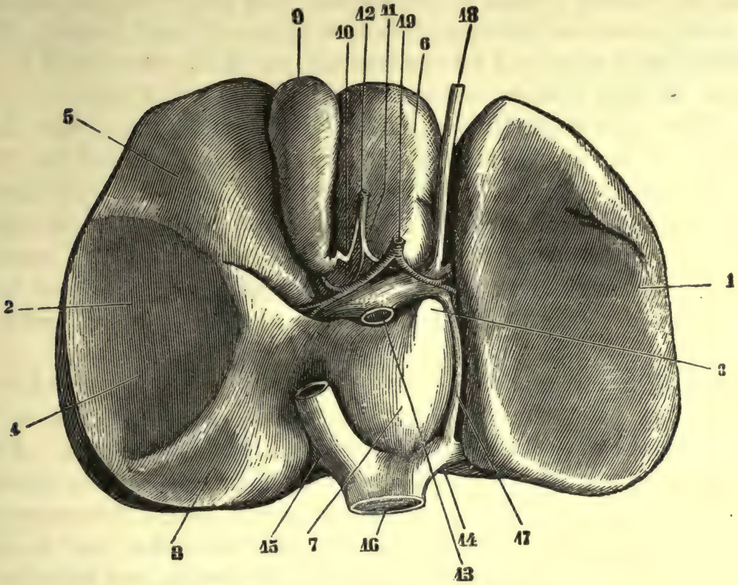

Fig. 28.—Liver of Man. (DUVAL.)

1, Left lobe. 2, Right lobe. 6, Lobus quadratus. 7, Lobus Spigelii. 9, Gall-bladder. 10, Cystic duct. 11, Hepatic duct. 12, Common biliary duct. 13, Portal vein. 14, 15, Hepatic veins. 16, Inferior vena cava. 19, Hepatic artery.

and the left vagus has some fibers going to it. The whole organ is insheathed in a very fine coat of areolar tissue known as Glisson's capsule.

Structure.

The hepatic substance is readily torn and has a granular appearance; these coarse granules, corresponding with the distinct spots seen on the surface, are polyhedral, and are the lobules of the liver. These lobules are $^1/_{12}$ inch in diameter. In studying the relation of these lobules to the blood-vessels and ducts of the liver, it is found that an extreme branch of the hepatic vein commences in the axis of every lobule and emerges at its base to join a larger branch. This connection of veins and lobules reminds one of the attachment of the leaves by their midribs and stems to the branches of trees.

The capsule of Glisson divides the liver-substance into these lobules, for the areolar tissue enters the transverse fissure of the liver.

Microscopically, each lobule is made up of epithelial cells, naturally spheroidal, but because of compression are more or less polygonal. These. the true liver-cells, are about $^1/_{1000}$ inch in diameter, containing protoplasm with large, round nuclei which have one or more nucleoli. The cells are held together by an albuminous cement-substance; in it are fine channels containing the bile-capillaries.

The *portal vein* also has its course in the portal canals, where it divides and subdivides. By its division *between* the lobules in the interlobular connective tissue it forms the *interlobular vein.* From this vein fine capillary branches are given off, which pierce the enveloping membrane of the lobule to find their way toward its center in a converging manner. In their course to its center they pass in close proximity to the hepatic cells, and it is here that the real secretion of the bile takes place. From the point of union of the capillaries in the center of the lobule there proceeds a single, straight vein, called the *intralobular vein.* Arrived at the base of the lobule, this vein empties its contents into the *sublobular* vein, a radicle of the hepatic vein, which empties into the inferior vena cava.

The hepatic artery does not furnish the blood for the secretion of bile. Its function is to furnish a blood-supply to Glisson's capsule and to the investment of the lobules and the walls of the bile-ducts.

The course of the *bile-ducts* is very similar to that of the portal vein and hepatic artery. Bile capillaries have no distinct walls of their own except those formed by the liver-cells between which they are situated. All cells, except those in contact with capillary blood-vessels, are completely girded with bile-capillaries. Intracellular passages pass from the bile-capillaries into the interior of the liver-cells. After numerous anastomoses, the bile-ducts form larger ones, to leave the liver through the hepatic fissure as two main branches. Toward the exit the bile-ducts become correspondingly larger, with increase in the thickness of their walls. These are found to contain fibrous tissue with bundles of nonstriped muscle-fibers plus small mucus-secreting glands. Within each lobule are three networks: a network of blood-capillaries, a network of liver-cells, and a network of bile-capillaries.

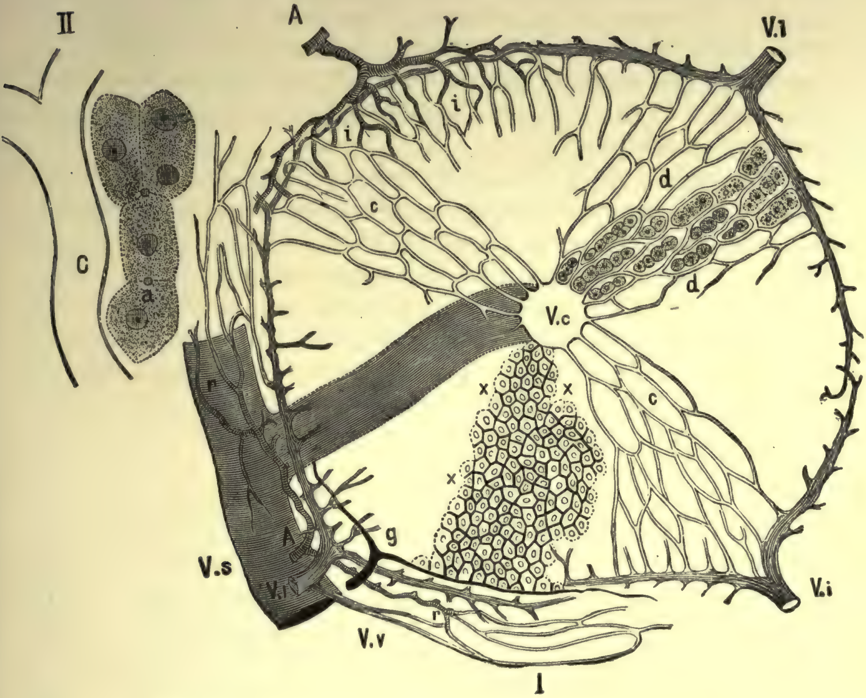

Fig. 29.—Diagrammatic Representation of an Hepatic Lobule. (LANDOIS.)

I. *Vi, Vi,* Interlobular veins. *Vc,* Central vein. *c,* Capillary between the two. *Vs,* Sublobular vein. *Vv,* Vascular vein. *A, A,* Branches of the hepatic artery, approaching the capsule of Glisson and the larger blood-vessels at *r, r,* and forming the vascular vein further on, entering the capillaries of the interlobular veins at *i, i.* *g,* Branches of the bile-duct, dividing at *x, x,* between the liver-cells. *d, d,* Situation of liver-cells in the capillary network. II. Isolated liver-cells, at *c* lying upon a capillary blood-vessel and forming a fine bile-duct at *a.*

The Gall-bladder.

The gall-bladder acts as the natural reservoir for storage of the bile. It is a pear-shaped bag of a musculo-membranous texture, capable of containing rather more than a fluidounce, and is situated upon the under side of the liver in a fissure fashioned for it. It is about four inches long, one inch at its fundus, or base.

The *structure* of the gall-bladder consists of three coats: an outer, *serous* coat; a middle, *fibrous;* and an inner, *mucous* coat. The fibrous coat contains both circular and longitudinal fibers. The inner surface of the bladder is lined with mucous membrane, which is of a yellowish-brown color.

The hepatic duct, formed by union of two bile-ducts issuing from the liver, is about one and one-half inches long. By its joining the cystic, also about one and one-half inches in length, is formed the common bile-duct, known as the *ductus communis choledochus.* This, the largest of the three, is three inches long, with the diameter of a goose-quill, emptying with the pancreatic duct into the duodenum through a common opening. The motor nerve of the gall-bladder is the vagus; the nerve which supplies the relaxing muscles of the gall-bladder is the sympathetic.

Functions of the Liver.

The liver, being such an important gland, naturally occupies a very prominent position in the general metabolism of the economy. Its principal functions are: the formation of an internal secretion, *glycogen;* the formation of urea; and, last, the production of the bile, in which as a vehicle many poisonous products are expelled.

Bile is a thick, golden-colored liquid of a very bitter taste. Its secretion by the liver represents only one subsidiary function of the many performed by this important gland. It represents waste albuminous matters, together with coloring pigments and mineral salts dissolved in water. Though primarily excrementitious substance and performing the necessary functions of such, it, however, possesses some powers to aid intestinal digestion, both directly and indirectly. These will be discussed under the head of the "Uses of Bile." The secretion of bile is an intermittent process, for a supply, though scanty, is intermittently passing into the duodenum. The arrival of chyme in the duodenum immediately calls for an increased amount, to be followed by a second increase some hours later.

Starling holds that the mechanism by which the increased secretion of bile is produced at the time when this fluid is required in the intestine, is identical with that for the secretion of pancreatic juice, and that in each case *secretin*—formed by the action of hydrochloric acid on the duodenal epithelium—is absorbed, and excites the liver and pancreas to increased activity.

Barbera has shown that a meat-diet excites the greatest secretion of bile, fat less, and a carbohydrate diet hardly any.

It is in the intermission between meals that the liver is least active, and it is then that only a small supply reaches the duodenum. It continues during pains the most violent, in intestinal congestion, and in peritoneal inflammations.

Contrary to the plan of all the other secreting and excreting organs, the main supply of blood to the liver, and from which its secretion, the bile, is formed, is *venous:* from the portal vein. The nutrient function of the hepatic artery is to supply structures and membranes only. Since the portal vein furnishes the supply, the bile is secreted at a very much lower pressure and therefore more slowly than those secretions from glands whose supply is arterial, as the pancreas and salivary glands. It is quite natural that a fluid so complex as the bile demands for its preparation a much longer period of time than one which contains only water, salts, and certain principles of the blood. Though not directly governed by nerve-influences upon the portal vein, the blood-supply to the liver is varied.

Compared with the size of the liver, the secretion is small and slow, and holds but little relation to the mass of blood traversing it. The quantity secreted *per diem* has been variously computed at two pounds. Its specific gravity in man averages 1.026; reaction, neutral or slightly alkaline.

Chemical Properties and Constituents of the Bile.

Bile mixes with water, producing no turbidity; heat produces no coagulation because of the absence of any coagulable proteids. Alcohol precipitates mucin, diastase, and bilirubin, if the latter is present. Acetic acid precipitates mucus; lead acetates, the biliary salts. When in contact, bile rapidly destroys the red blood-corpuscles.

Bile contains both organic and inorganic materials. Those organic are mucin, biliary pigments, biliary salts, cholesterin. lecithin, neutral fats, soap, urea, and diastase. In organic matters are water, chloride of sodium, and phosphates of iron, calcium, and magnesium.

The means by which the various components of the bile are formed is as yet not thoroughly understood. Some of its constituents may exist in the portal blood; thus the pigment is produced by the decomposition of the blood. If hæmoglobin itself or substances which are capable of separating the coloring matter from the red corpuscles be injected into the portal blood, there is a proportionate increase in bile-pigment. Biliary acids are not preformed in the blood, for upon extirpation of the liver there follows no appearance of them in the blood. Evidently the hepatic cells must exert some functions as yet not understood.

The composition of human bile is approximately as follows:—

Water			982	parts in 1000.
Solids	Mucin and pigments	1.5	18	
	Bile-salts	7.5		
	Lecithin and soaps	1.0		
	Cholesterin	0.5		
	Inorganic salts	7.5		

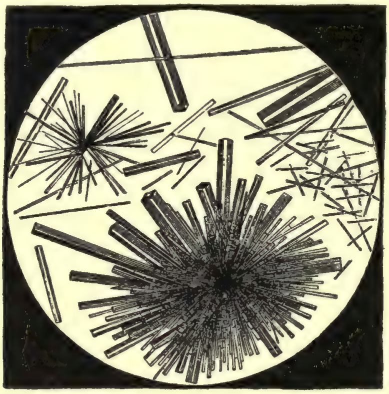

Fig. 30.—Glycocholic Acid. (Duval.)

Bile-mucin.

The latest investigations show that human bile contains real mucin.

Bile-salts.

There are two salts of bile, both having sodium as a base. These are glycocholate and taurocholate. These two acids are very closely related to each other, for, on boiling with stronger acids, a common nonnitrogenous body is obtained called cholalic acid, and an amido-acid which contains nitrogen. The glycocholic acid gives glycin and the taurocholic acid gives taurin, which contains sulphur. Taurin, from its sulphur-content, must be a result of the metabolism of the proteids, and, according to Friedmann, it comes from cystin. Hence the bile-acids represent the final changes of the proteids of the liver-cell. In man these acids exist in variable proportions. The bacteria of the intestinal canal break up the bile-salts.

Glycocholic acid is a monobasic acid, crystallizing in long, fine needles. Taurocholic is also monobasic; it crystallizes with great difficulty, forming fine, deliquescent needles, which in solution have a bitter-sweet taste. Proteid is the source of glycin and taurin.

Subcutaneous and venous injections of bile-salts cause coma and depression.

Hay's Sulphur Test for Bile-salts.—On the surface of bile or a solution holding bile-salts, sprinkle flowers of sulphur; it will sink to the bottom of the tube, while on most other liquids it will float.

The bile-salts lower the surface tension of fluids in which they are dissolved.

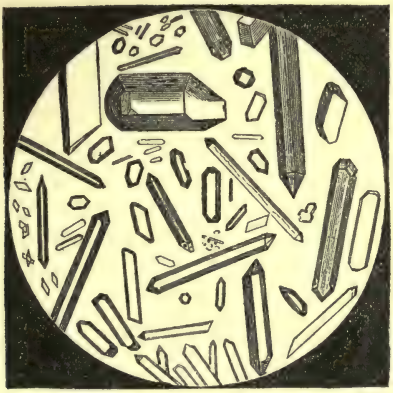

Fig. 31.—Taurin. (DUVAL.)

Pettenkofer's Test for Bile-acids.—To a nearly equal volume of bile add a drop or two of syrup of cane-sugar (10 per cent.). Pour concentrated H_2SO_4 at the line of junction of the two fluids, then a purple color is obtained. The purple color produced shows absorption bands in the spectrum. The acid on the cane-sugar produces a body called furfuraldehyde, which sets up a reaction with the cholalic acid to produce the color.

The Bile-pigments.

Normally, the color of the bile is due to the presence of but two bile-pigments: *bilirubin* and *biliverdin*. When pathological, other characteristic ones have been described. Depending upon the proportion of each present, the color may range from reddish-brown to grass-green. They are formed from the hæmoglobin of the blood—the mother of all the bile-pigments. In man and carnivora bilirubin predominates and gives to the bile its yellow color; the green color of that of herbivora is due to biliverdin.

Bile contains neither bilirubin nor biliverdin free, but combinations of these two substances as salts: bilirubinates and biliverdinates of the alkalies. The bilirubinates are transformed into biliverdinates by the oxygen of the air. These bodies, bilirubin and biliverdin, act as acids.

Bilirubin, isomeric with hæmatoporphyrin, represents the iron-free pigment of the bile; its formula is $C_{16}H_{18}N_2O_3$. This is the permanent pigment of the bile and may also appear as a calcium compound in red gall-stones. When exposed to the air and in an alkaline solution, it oxidizes very readily, changing into biliverdin; because of this, bile, when standing, assumes a greenish tint.

Biliverdin is present in all biles of a greenish color. It occurs as such in the liver-secretion of herbivora, but may be obtained by allowing human and carnivorous bile to oxidize slowly by exposure to the air. Its formula is $C_{16}H_{18}N_2O_4$, having one more atom of oxygen than bilirubin.

When bilirubin arrives in the intestine the bacteria generate nascent hydrogen, which reduces it and generates another pigment, the coloring matter of the fæces, called stercobilin. This stercobilin when absorbed and excreted in the urine is called urobilin.

Gmelin's Test for Bile-pigments.—Add to some bile some nitric acid containing nitrous acid, when there will be a play of colors: green, blue, purple, and yellow. These tints are due to the oxidation of bile-pigments. The green is biliverdin; the blue, bilicyanin; the purple, bilipurpurin; and the yellow, choletelin.

Cholesterin.

Cholesterin is a monovalent alcohol. It is present to some extent in all protoplasmic structures,—blood-corpuscles,—but particularly in bile and nervous tissues. In the latter it forms a very important part of myelin. In the bile it forms but a small proportion of its contents—from 1 to 5 per cent. It is insoluble in water and dilute saline solutions, but readily soluble in ether, chloroform, alcohol, etc.; in this respect it resembles fat, though not a true fat. In bile it is readily dissolved, because of the presence of bile-salts. If, for any reason, the latter should be insufficient, the cholesterin passes out of solution to form concretions around any foreign particles or previously hardened concretions, forming a gall-stone in man. Another kind of gall-stone is bilirubinate of calcium, rare in man, but frequent in the ox. Besides its characteristic crystals, cholesterin is also detected by various color-reactions in the presence of iodine and sulphuric acid.

The general presence of cholesterin in so many parts and cells of the body leads to the impression that it is a cleavage product of metabolism, being one of the waste-elements in the life of the cell, especially the nerve-cell. Being absorbed by the blood, it finds its way to the liver, there to be elaborated and to appear in the bile. The cholesterin of the bile is now generally admitted to be drawn from the cells lining the bile passages and gall-bladder. In catarrh of these passages the amount of cholesterin is increased so much that bile salts cannot keep it in solution, and the formation of gallstones is accelerated. Being an excrement, it is not reabsorbed, but is expelled from the economy as a part of the fæces. Pathological changes in tissues are always marked by an increased quantity, which may be accounted for by loss of vitality in the diseased cells so that they are unable to break down the cholesterin.

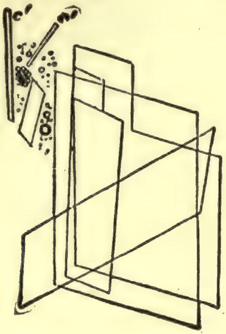

Fig. 32.—Crystals of Cholesterin. (Duval.)

Cholesterin is not poisonous to animals.

Lecithin is found chiefly in nervous tissues, red corpuscles, and the bile. It is most abundant in the nervous system. This is a compound of a nitrogen base, cholin, with glycero-phosphoric acid with fatty acid radical. Combined with a carbohydrate residue, it is found in the liver, and is then called jecorin.

When lecithin is taken by the mouth it is broken up in the intestine into cholin, a poisonous alkaloid; but the intestinal bacteria destroy it at once, producing methane, carbonic acid, and ammonia.

Uses of Bile.

In fasting, not a drop of bile enters the intestine. Fat, meat extractives, and the products of digestion of egg-albumin set up a free discharge of the fluid. Bile accentuates the activity of the pancreatic enzymes, especially the fat-splitting ones, the action of which is increased twofold. The pancreatic secretion, in its hourly rate, corresponds closely with the entry of bile into the intestine under the same conditions of diet. The similarity is most striking. Bile arrests the action of pepsin, which is injurious to the ferments of the pancreatic juice, and favors the ferments of the latter, especially the fat-splitting one.

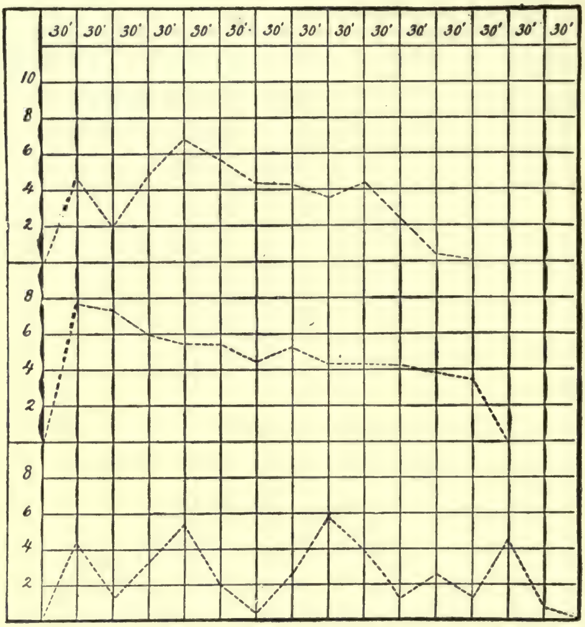

Fig. 33.—Curves Showing the Velocity of Secretion of Bile into the Duodenum on (1) a diet of milk, uppermost curve; (2) a diet of meat, middle curve; (3) a diet of bread, lowest curve. The divisions on the abscissa represent intervals of thirty minutes; the figures on the ordinates represent the volume of secretion in cubic centimeters. (Howell, after Bruns.)

Bile is principally excrementitious. It partly emulsifies the fats and contributes to their solution by the soap which the alkalies of the bile produce. The emulsification of fat is a mechanical preparation of it, in order that lipase may act upon it. By thus rendering the fats alkaline in part they are able to come in closer touch with the intestinal mucous membrane, and to be absorbed by it. Endosmotic experiments have proved that the fats are imbibed and that they traverse more easily membranes that are impregnated with an alkaline solution than those simply wet with water. Experimentally, when the bile is turned out of its course, the chyliferous vessels are not filled with white, milky fluid, since only one-seventh of the normal amount of chyle is absorbed.

When the chyme passes into the duodenum, the glycocholate and taurocholate of sodium are broken up by the acid in the chyme to form sodium chloride, at the same time setting the bile acids free. Immediately they are precipitated, carrying down with them the pepsin, making the chyme alkaline and more turbid, due to the precipitation of the unpeptonized proteids. This thickening of the stomach contents aids very materially in slowing the movements of the digested products through the intestines, thus giving the villi and blood-vessels more ample time to absorb nutritious substances.

By rendering the chyme alkaline, it aids the action of the pancreatic juice, which is most effective as a digestive agent in an alkaline medium, at the same time favoring absorption, since alkaline liquids permit of more ready osmosis.

The bile itself easily becomes putrid on standing. How can it prevent the putrescence, then, of the intestinal contents? That it does in some way diminish this degenerative process is very evident, for, when the common biliary canal is ligated, the fæces are more fœtid and the intestinal gases more abundant. The bile's so-called antiseptic powers must be accounted for by its hastening absorption and assisting it to such an extent that the quantity of matter capable of putrefaction is greatly diminished in quantity. Bile, as a rule, increases peristaltic contraction of both the large and small intestine. Taurocholic and glycocholic acid act in the same manner. But bile also can at times retard the intestinal movements with or without subsequent acceleration of the peristaltic act.

By this action the economy possesses a natural purgative. By it, as a stimulus, the secretion of the glands of the intestinal mucous membrane is increased, and more rapid peristaltic movements of the intestinal muscles induced to aid in the propulsion of their contents.

Reabsorption of Bile-salts.

When it was ascertained that the bile-salts were the products of the hepatic cells, that only a small proportion appeared in the fæces, with a still smaller proportion in the urine, the question arose: Is the remainder reabsorbed by the intestines to be again secreted from the blood by the hepatic cells?

Bile-salts taken by the mouth produce an increased flow of the bile, which is at the same time higher in its percentage of proteids. Dog's bile, containing normally only taurocholate of sodium, has been found to contain glycocholate, when that salt had been injected into the animal's blood. Again, when bile has been taken from an animal for some time by a fistula, its quantity of solids diminishes, showing that the hepatic cells cannot give back these salts to it when the portal blood does not convey to them the materials for their formation. From these and other facts it was deduced that there must exist in the body reabsorption of bile-salts.

Antitoxic Function of the Liver.—It was found that nicotine added to the portal blood of an experimental circulation through the liver soon vanishes. Similar experiments with strychnine, morphine, and quinine resulted in the same way. These alkaloids are not only deposited in the liver-cells, but they experience a change in their chemical constitution by which they lose their poisonous properties. It is well known that the liver is a storage for the metallic poisons mercury, arsenic, iodine, and antimony for long periods. The liver also transforms the bodies developed by action of intestinal bacteria on proteid. I refer to indol and phenol. Here the liver exerts a protective action against poisoning by these bodies.

When the liver is removed, certain nervous symptoms supervene, such as somnolence, ataxia, convulsions, and coma. This is supposed to be due to the ammonia salts, generated in proteid digestion, getting into the blood. When the liver is present, they are converted into urea.

The liver also reduces the toxic activity of poisons generated by specific bacteria, as by the typhoid bacilli and tetanus organisms. The liver is probably the seat of most active oxidations, and it is by these chemical activities that it acts as a protective agent against poisons.

Internal Secretion of the Liver (Glycogen).—Besides secreting the bile to be partly used in digestion, but mainly as an excrementitious substance, the liver possesses still another remarkable function.

namely: separation from the portal blood by its cells of a substance known as glycogen, or animal starch.

Glycogen exists constantly, though in very small proportions, in protoplasm and animal membranes in general; also, in white blood-corpuscles and pus. It occurs in more considerable quantities in liver, muscle, and embryonic tissues after the third month. Glycogen is a white, tasteless powder, soluble in water, but producing an opaque solution. Glycogen possesses the property of being readily transformed into glucose, to be ready for easy oxidation. Glycogen with iodine in solution with iodide of potassium gives a port-wine color, which disappears upon heating.

Naturally during absorptive processes following active digestion, portal blood contains more than the normal quantity—1 per 1000. At the very same time the blood in the hepatic vein during the intervals of absorption of carbohydrates contains 2 parts per 1000. Within the hepatic-cell protoplasm glycogen is deposited. When an excess of carbohydrates is taken, not all of the glycogen can be absorbed, but passes through into the general circulation, to be deposited in the muscles and other tissues. Muscles may contain as much as 1 or 2 per cent.

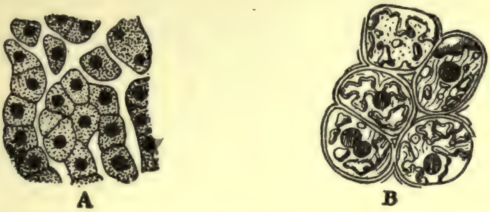

Fig. 34.—*A*, Liver-cells during fasting. *B*, Cells filled with Glycogen. (HEIDENHAIN.)

That sugar should appear in both portal and hepatic blood is not to be wondered at. when carbohydrates are fed, but that it should still be present when but meats are given, or when the portal vein is ligated at the transverse fissure, goes far to prove that glycogen, or sugar-forming animal starch, must be manufactured within the parenchyma of the liver. Even when an animal is made to fast, and at the same time perform very severe muscular work, so that glycogen disappears in muscles and liver, its presence in the liver is soon ascertained again though the animal be fed but gelatin.

Since neither glycogen nor sugar appears in the bile, it follows that it, or some transformed product of it, must be absorbed into the blood before it can serve any needs in the economy. From our data we are led to believe that the glycogen is formed and stored up in the liver-cell protoplasm, and the appearance of sugar is due to its transformation by *liver diastase,* to be absorbed into the hepatic veins.

Glycogen is formed most abundantly from carbohydrate food and from fats (Pflüger), and next from proteids. On a diet rich in carbohydrates, the glycogen of the liver reaches 15 per cent., while in a state of starvation it may be so small as to escape the tests.

Uses.

The liver is the chief storehouse of the carbohydrate material. Thus the use of the glycogenic function of the liver is supposed to be that of continuously supplying material which may be easily oxidized for the purpose of maintaining animal heat and motion. Sugar is a very unstable article in the presence of oxygen with albuminoid substances. The sugar becomes oxidized, both in the blood during respiration as well as in the tissues supplied by the blood.

DIABETES.

Diabetes is a chronic affection characterized by the constant presence of grape-sugar in the urine, an excessive urinary discharge, and progressive loss of flesh and strength. Its exact pathology is as yet unknown, but seems to be intimately associated with certain nervous affections, disturbed hepatic and pancreatic functions, sexual excesses, while heredity also seems to play an important rôle.

Simple Glycosuria must be differentiated from the disease diabetes (mellitus), since the former is but a temporary *condition,* and not a disease. When excessive quantities of sugar, maltose, etc., are eaten by a perfectly healthy individual, sugar appears in the urine, due to the fact that all of the absorbed sugar cannot be carried into the portal circulation fast enough, so that some finds its way into the thoracic duct and by it is emptied at once into the general circulation. Before reaching the liver, where it would be stored up as glycogen, it passes through the kidneys, there to be promptly eliminated. This temporary condition has been termed *simple,* or *alimentary, glycosuria.* Dietary conditions, in the way of abstaining from starchy and saccharine foods, will promptly eradicate this condition. Simple glycosuria may also result from the inhalation of chloroform, turpentine, use of chloral, etc.; it may be one of the conditions following injury to the head. Diabetic glycosuria differs in this, that sugar is *constant* and is not made more significant by the presence of large quantities.

We know from our study of the glycogenic function of the liver that glycogen can be produced from proteids by synthesis after the proteid molecule has been first broken down.

If from any cause, nervous or otherwise, the metabolism of the liver is interfered with, the function of glycogenesis is disturbed, and the balance broken, with the result of the appearance of sugar in the urine.

Experimental diabetes may be produced in animals in various ways:—

1. By Diabetic Puncture.—It was discovered by Bernard that certain lesions to the cerebro-spinal axis, such as puncture of the floor of the fourth ventricle, are capable of producing diabetic conditions. After puncture, the glycogen of the liver is so rapidly converted into sugar, that it raises the percentage of sugar in the blood to such a degree that there is more present than the tissues can use up, and thus some of it finds its way to the kidneys, there to be eliminated. The increased activity of the hepatic cells in transforming the glycogen is believed to be due to stimulation of the vasomotor center in the medulla caused by the puncture, for other means of stimulating this center have always produced temporary diabetes. In man, some diseases of the brain, particularly those in the medullary region, are characterized by diabetic symptoms.

2. Adrenalin Glucosuria.—Injection of adrenalin produces diabetes. It is due to a hyperglycæmia. There is an increase of glucose, due to a decrease in its destruction. The ammonia excretion is considerably increased. Hence, in Bernard's puncture, there is an overproduction of dextrose by the liver; in pancreatic diabetes, a want of destruction of glucose in the body. In phloridzin diabetes, there is production of sugar by the renal cells, and in diabetes mellitus, a hyperglycæmia, and this is due to a want of destruction. The sugar in diabetes mellitus is derived from carbohydrates, proteids, and fats.

3. Phloridzin.—This drug is a glucoside obtained from the root-bark of cherry-trees. Powerful results are obtained after its administration either by the stomach or by subcutaneous or intravenous injection. With the appearance of the sugar in the urine, there is a diminution in the quantity of glycogen in the liver. If the drug be administered repeatedly, so that all of the glycogen from the liver and other tissues is entirely used up, and then an additional dose be administered, dextrose will promptly appear.

PHLORIDZIN DIABETES.—Here the ratio of dextrose to nitrogen excreted in starving animals is about the same as in pancreatic diabetes, as has been shown by Lusk. The proportion is 3.5 to 1. In phloridzin diabetes, just as in pancreatic diabetes, the tissue proteid is the source of the sugar, and these two forms of diabetes are identical as regards their cause. In phloridzin diabetes, the organism has not lost the power of oxidizing glucose, as in pancreatic diabetes or in diabetes mellitus. Phloridzin diabetes is not hyperglycæmia. Pavy and Brodie have shown that the sugar is formed in the kidney itself, out of serum-proteid in the blood. Phloridzin confers a secretory power on the renal cells. Beta-oxybutyric acid also appears in the urine after prolonged administration of phloridzin.

To epitomize: Diabetes appears (1) after the use of certain agents, adrenalin, iodothyrin, and particularly phloridzin; (2) after inhalation of chloroform and amyl nitrite; (3) after puncture of the medulla oblongata; (4) by section of the spinal cord above the exit of the hepatic nerves, probably by a paralysis of the vasoconstrictors of the liver; (5) by irritation of the central ends of the vagus and depressor; (6) by extirpation of the pancreas.

The majority of cases of true diabetes terminate fatally. Death is due to exhaustion and blood-poisoning, producing, just previous to the end, a condition of complete coma called acetonæmia.

Beta-oxybutyric acid is the chief acid in diabetic coma. It is believed to be produced by the excessive metabolism of proteid. Whenever a patient passes more than five grains of oxybutyric acid daily then the danger of acid intoxication must be watched. As to the estimation of the beta-oxybutyric acid, it can be made by ascertaining the amount of ammonia excreted, as it gives a rough index of the excretion of the acid. Thus, a daily output of ammonia of two grams corresponds to about six grams of the acid.

The supply of ammonia which can be used to neutralize acids is derived from the metabolism of cells and from the decomposition chiefly of meat used as food. In the beta-oxybutyric acid intoxication, this ammonia, instead of forming urea, goes to neutralize the acid, and is excreted in the urine as an ammonium salt.

The treatment of this diabetic coma is by sodium bicarbonate, by intravenous injection and by mouth.

CONJUGATED SULPHATES.

The aromatic products which are formed in the intestine—such as indol, skatol, phenol, and cresol—are eliminated by the kidneys in the form of sulphates. The aromatic bodies are absorbed by the portal vein and in the liver unite with suphuric acid produced by the oxidation of the sulphur of the proteids.

UREA AND URIC ACID.

The liver receives products from the muscles, as ammonium carbonate, and builds it into urea. It also destroys uric acid.

Jaundice is a discoloration of the skin due to the reabsorption of bile by the lymphatics of the liver. This is usually due to obstruction of the bile-ducts by a catarrh, a calculus, or a tumor. Arsenuretted hydrogen and toluylendiamin will produce jaundice.

Influence of Drugs on Secretion of Bile.—Podophyllin, aloes, nitrohydrochloric acid, ipecacuanha, euonymin, and sodium phosphate stimulate the bile-secreting apparatus. Other substances, like calomel, stimulate the intestinal glands, but not the liver-cells. The best stimulant of the liver is bile-acids in ox-gall, but it is important to remember that bile in the intestine is liable to be absorbed; hence it is best to combine a purgative with it to carry it down the intestinal canal.

THE SUCCUS ENTERICUS.

By most physiologists the presence of a certain liquid product, occurring upon the surface of the intestinal mucous membrane, is attributed to the secretory powers of the crypts of Lieberkühn and the glands of Brunner, presumably due to their columnar cells, although the real mechanism of its secretion is still unknown. To this secretion the name *succus entericus* has been commonly given. As described by Thiry, it is "a limpid, opalescent, light-yellow-colored fluid, strongly alkaline in reaction, and possessing a specific gravity of 1.010." It contains proteid and mucin, while its great alkalinity is due to the presence of a considerable quantity of sodium carbonate; the latter's presence is easily detected by the effervescence, resulting upon mixture with dilute acids. The amount secreted daily is, perhaps, about two pounds. Erepsin, a ferment found in the succus entericus, does not act on albumins, but breaks up albumoses, peptones, casein, protamin, and histon, changing them into leucin, tyrosin, and ammonia.

The succus entericus also contains a ferment like that in yeast —invertin. This body inverts cane-sugar into dextrose and lævulose, and maltose into two molecules of dextrose. On cane-sugar it acts as follows:—

$$\underset{\text{Sucrose.}}{C_{12}H_{22}O_{11}} + \underset{\text{Water.}}{H_2O} = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + C_6 + \underset{\text{Lævulose.}}{C_6H_{12}O_6}$$

This inversion is necessary for the absorption of these sugars.

All sucklings, including the new-born child, have lactase present in the pancreatic and intestinal juice. Weinland has shown that a dog fed on milk-sugar develops lactase in the pancreatic juice whilst it normally contains little or no lactase.

Maltase is also said to exist in the intestinal juice, splitting the maltose into dextrose.

The succus also contains another ferment known as enterokinase —a ferment of ferments.

This ferment augments the activity of the pancreatic ferments, especially the trypsin, by converting the trypsinogen of the pancreatic juice into trypsin. When dogs are fed only on starch and fatty foods, then the pancreatic juice contains trypsinogen with the object of protecting the amylopsin and steapsin. If the dogs were fed on meat exclusively, then the pancreatic juice contained mainly the ferment in the shape of trypsin. Unlike the stomach, mechanical irritation of the intestine calls out increased secretion of the succus entericus. But the intestine has a special stimulus, and that is the pancreatic juice. If a little pancreatic juice is inserted into a loop of the intestine for half an hour, then a fluid will be secreted containing much enterokinase. Every cannula introduced into an intestine acts as a foreign body and excites a secretion of water, with the object of washing it out of the intestine, and the amount of enterokinase becomes steadily less and less. Hence a mechanical stimulus calls out only water, and explains the severe diarrhœa of acute enteritis, while the ferment enterokinase is called out by the pancreatic juice.

Secretin injected into the circulation causes a secretion of intestinal juice.

INNERVATION OF THE SMALL INTESTINE.

If a piece of the small intestine between two ligatures has the nerves going to it divided, then we have a paralytic secretion. A similar state of affairs ensues after section of the nerves supplying the submaxillary gland. In the intestinal segment with its nerves divided will be found an abundant supply of intestinal juice, containing enterokinase and erepsin. This effect is probably due to section of nerves which normally inhibit the secretion. The contiguous intestinal segments with intact nerves are nearly empty.

DIGESTION IN THE LARGE INTESTINE.

Besides the changes wrought upon the foodstuffs in the mouth, stomach, and small intestine by the various digestive secretions with their powerful enzymes, there is still another more or less active agency in the form of *certain bacteria* which occur normally in health in varying amounts. Strassburger states that 128,000,000 bacteria may be found in a day, chiefly in the large intestine. They are swallowed by the mouth with the food, drinks, and saliva. The bacteria are one-celled organisms and are produced with marvelous rapidity. From a physiological point of view we are able to classify them into three groups: (1) fermenting, (2) chromogenic, and (3) pathogenic bacteria. However, only the ferment bacteria interest us.

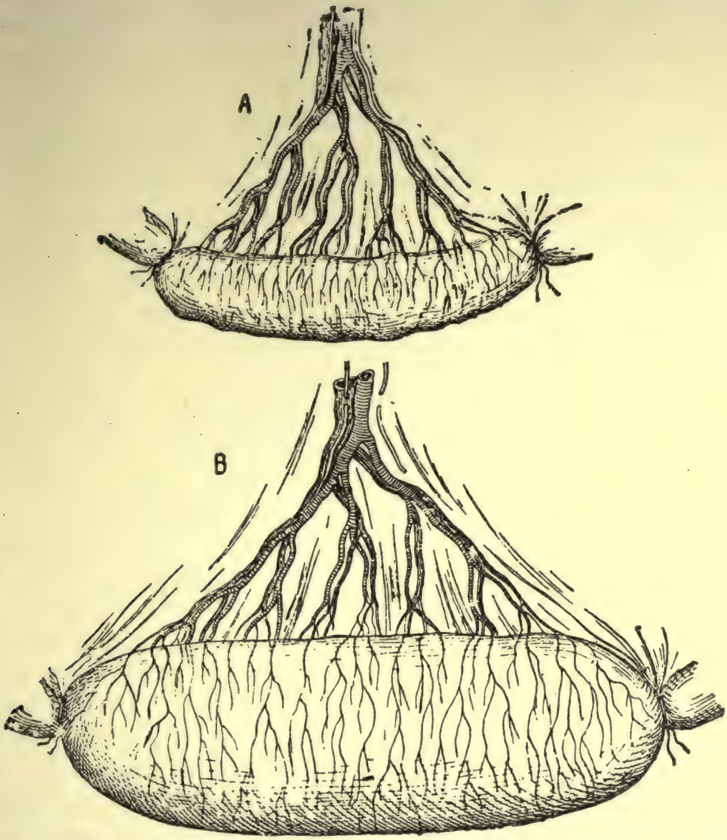

Fig. 35.—Aspect of an Intestinal Loop before and after Section of its Nerves. (ARMAND MOREAU, from GLEY.)

_A_, Normal segment of intestine. _B_, Same segment several hours after section of its nerves. The nerves are represented by fine lines. The distension of the intestine is often much greater than indicated in the figure.

Bacteria of different kinds have been noticed at various times throughout the entire alimentary canal from mouth to anus, but are more numerous in the intestines, particularly in the large one, where their action is very marked upon matters reaching it, so as to give rise to the term "bacterial digestion." In the stomach, under normal conditions, the putrefactive activity of the bacteria is neutralized and the germs themselves are killed by the free hydrochloric acid of the gastric juice. It is in the intestines, where the secretions are alkaline, that the best media are found for their culture and development.

It has been suggested that bacterial digestion was necessary to the economy, because it accomplishes so many things. But it has been shown by Nuttal that, by removing guinea-pig fœtuses directly by incision from the uterus, and with antiseptic care, and then keeping them in a sterile chamber, receiving sterilized air and fed on sterile milk, they grew. When their intestinal contents were examined no bacteria were found. Hence the inference is that bacteria are not necessary for good digestion.

The two chief bacteria are the lactic acid bacillus and the colon bacillus. The former is found in the stomach at times and the upper part of the small intestine. The colon bacillus chiefly lives in the colon. These bacteria are aërobic; that is, they consume oxygen in the action. Hence they are powerful reducing agents. Thus they take oxygen from bilirubin and form stercobilin. But, although these microbes use oxygen, they can also live without it. On proteids the bacteria produce by their action proteoses and peptones, and from tyrosin the aromatic bodies: phenol and cresol. Indol and skatol are derived from tryptophane. On carbohydrates the bacteria act like ptyalin and amylopsin; on fats they act like steapsin, breaking up lecithin into cholin. Bacteria in the stomach and intestine can set up five kinds of fermentation: (1) alcoholic; (2) acetic; (3) lactic; (4) butyric; and (5) a form of fermentation discovered by Drs. Herter and Baldwin—the oxalic acid variety. These fermentations may give rise to acute and chronic gastro-enteritis. In the intestine the fermentations will give rise to excessive distension, diarrhœa, colic, and a loss of weight and strength. The remote effects of these fermentations will be an increase of uric and oxalic acid in the urine and of the acidity of the urine itself, causing frequent urinations, especially at night. The best indication of intestinal putrefaction is the aromatic or ethereal sulphates which appear in the urine. The easiest test to detect the indoxyl sulphate of potassium is the indican reaction.[1] These bacteria also help form the gases of the intestine by a fermentation of the food. The gases in the intestine are nitrogen, carbonic acid, hydrogen, sulphuretted hydrogen, and carburetted hydrogen. The large intestine is not necessary to life, as the cure of chronic constipation has been accomplished by resection of the intestine.

THE FÆCES

The foods that have failed to be absorbed, after having remained about three hours in the small intestine, pass into the large intestine, where they remain for about twelve hours. The quantity and consistency of that secreted daily by an adult varies within wide marks, depending upon the kind of diet, and the length of time the foodstuffs remain within the intestine. The adult eliminates about 8 ounces of moist excrement *per diem*. From a vegetable diet the fæces are both softer and contain a higher percentage of solids, than from a meat diet; softer because their irritations to the intestinal walls heighten mucous secretion and increase peristalsis, thereby hastening its passage, to the detriment of absorption. In a meat diet the want of this stimulation retards defecation to such an extent

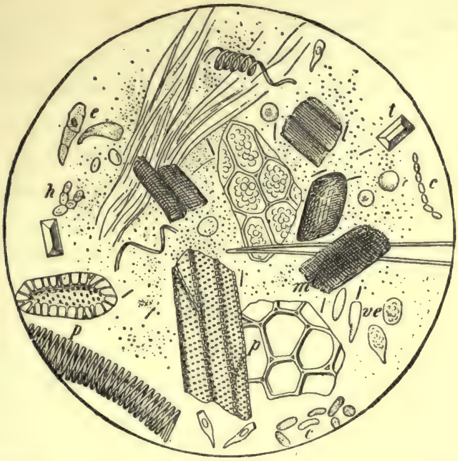

Fig. 36.—Stool. Collective Microscopic Picture. × 350. (Partly after Nothnagel.) (Lenhartz.)

m, Muscle-fiber. *e*, Intestinal epithelium. *ve*, The same, "broken down." *c*, Clostridium butyricum. *h*, Yeast. *p*, Vegetable cells. *t*, Triple phosphate.

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[1] Herter, "Chemical Pathology."

that it may occur but once in several days. The stools are then small in amount and dark in color. The stimulating action of vegetables is what makes them so valuable in mixed diets, though they are inferior in nutritive value, bulk for bulk.

Although the fæces are so variable quantitatively, they are more consistent qualitatively, and present the following substances:—

I. Water.—In health about 75 per cent.; this becomes much greater during diarrhœa.

II. Indigestible Residue of different foodstuffs, as nuclein, keratin, from epidermic structures, hæmatin from hæmoglobin, ligaments of meat, cellulose from vegetables, mucin, wood-fibers, gums, resins, and cholesterin.

III. Undigested Food.—The quantity of food ingested has an effect. The more one eats, the more likely he is to have a quantity of undigested matters in the stool. These undissolved substances are usually pieces of vegetables, muscle-fibers, connective tissue, and small quantities of casein and fat. These materials help to accelerate peristalsis and so interfere with a proper absorption of those foods that would otherwise be readily taken up.

IV. Mucous Epithelial Cells.—The microscope shows these are present from the intestinal surface.

V. Derivatives of Bile-salts and Bile-pigments.—These are stercobilin, cholesterin, traces of bile-acids, and lecithin.

VI. Number of Putrid Products, as skatol, indol, phenol, volatile fatty acids, ammonia, sulphuretted hydrogen, and methane.

VII. Inorganic Salts.—These are salts of sodium, potassium, calcium, magnesium, and iron.

VIII. Micro-organisms.—Bacteria of numerous kinds are present in the fæces.

The coloring matter is stercobilin. The odor is due to skatol and indol.

The fæces in part are a product of secretion of the intestine itself. Hence the nitrogen of the fæces comes not only from indigestible food, but also from the secretion of the intestine, and thus is a partial index of metabolism.

The Color depends upon the kind of food ingested; meat gives dark-brown or black, vegetables light-yellow, fæces. The reaction is normally alkaline in adults, while in infants it may be acid and yet not pathological.

Meconium is the name given to the greenish-black contents of the large intestine of the fœtus which is expelled at or after birth.

It is chiefly concentrated bile with intestinal epithelium. The coloring matter is a mixture of bilirubin and biliverdin, not stercobilin.

Defecation.—The act of defecation is, to a *slight extent, voluntary,* being in *the main involuntary.* In order that the fæces may not stimulate mechanically the sphincter reflexes so that they relax at any time, volition plays a rôle. For there is a center, having its seat in the brain, which is inhibitory, and by voluntary impulses the individual is capable of relaxing or increasing the contraction of the external sphincter ani.

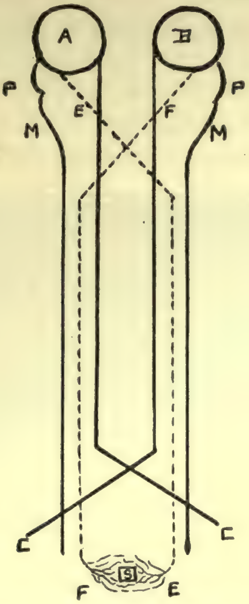

Fig. 37.—Inhibitory Apparatus of Ano-spinal Center.

A, *B*, Locus niger of Cerebral crura. *E*, *F*, Inhibitory fibers. *P*, Pons. *M*, Medulla oblongata. *C*, *C*, Sensory fibers. *S*, Ano-spinal center.

The inhibitory apparatus of the ano-spinal center arises, according to the latest researches that I have made upon the subject, from the locus niger of the crura cerebri. From this point inhibitory fibers descend, some of which commence to decussate at a point in the pons down to the nib of the calamus scriptorius, and then pass down the lateral columns. Some of the fibers, not decussating, also pass down the lateral column. This inhibitory apparatus is under the control of a center in the cortex. I might add here that the same inhibitory apparatus presides over the sphincter vaginæ.

When a sufficient quantity of fæces has arrived in the lower part of the rectum, there is felt a need of expelling them. During defecation all the organs situated in the abdomen are compressed so that the intestinal contents may be expelled, but the anal sphincter, like the cardiac sphincter of the stomach, offers a resistance, and during the violent efforts the vesical sphincter is relaxed, allowing the urine to escape. The sensory nerve-endings in the mucous membrane of the rectum carry impressions to the ano-spinal center in the lumbar cord, which sends out motor impulses to the muscles of the intestine. At the same time the glottis is closed, the diaphragm and abdominal muscles are set into action, and the act of defecation is accomplished.

Section of cerebral crura, that is, the locus niger, permits the anal and vaginal sphincters to take on rhythmic contractions.

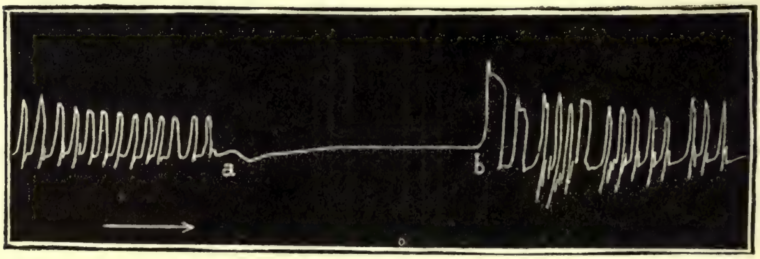

Fig. 37a.—Rhythmic Systolic Movements of the Anal Sphincter of Cat after Transverse Section of Lumbar Part of Spinal Cord. Rubber Balloon in the Rectum Connected with Marey's Polygraph. (OTT, from LUCIANI.)

At *a*, irritation of the sciatic, the rhythm of the sphincter is inhibited. By *b*, irritation stopped, the rhythm starts up again stronger and somewhat irregular.

Nutrient Enemata.—Enemas have been shown to travel by antiperistalsis up the large intestine, through the ileo-cæcal valve and into the small intestine, where there is no antiperistalsis. The normal antiperistaltic movements of the ascending colon seem to be effective factors in propelling these enemas into the small intestine. Hence nutrient enemas are absorbed.

HUNGER AND THIRST

The seat of sensations of hunger is located in the epigastrium. The seat of sensations of thirst is located in the pharynx, and is quieted by intravenous injections of water. In every case it is admitted that hunger and thirst are but localized expressions of a general need of the blood for food and drink. The true seat of

Résumé of Action of the Digestive and Liver Ferments.

CLASS OF ENZYME.	NAME OF ENZYME.	DIGESTIVE FLUID IN WHICH FOUND.	CONCISE DESCRIPTION OF SPECIFIC ACTION.
Amylases or Amylolytic.	1. Ptyalin.	Saliva.	Convert amyloses (starch and glycogen) into dextrin, maltose, and isomaltose, accompanied by glucose.
	2. Amylopsin.	Pancreatic Juice.	
Proteases or Proteolytic.	1. Pepsin.	Gastric Juice.	1. Converts proteids into proteoses and peptones.
	2. Trypsin.	Pancreatic Juice.	2. Converts proteids into proteoses, peptones, and amido-acids.
	3. Erepsin.	Succus Entericus.	3. Converts peptones into leucin, tyrosin, and ammonia.
Steatolytic or Lipases.	Steapsin.	Pancreatic Juice.	Splits up neutral fats into fatty acids and glycerin.
Coagulases.	1. Rennin.	Gastric Juice.	1. Coagulates milk, converting caseinogen in presence of calcium salts into casein.
	2. Rennin.	Pancreatic Juice.	2. Coagulates milk.
Invertase.	Invertin.	Succus Entericus.	Inverts maltose into dextrose and lævulose.
Kinase, ferment-increasing power of other ferments.	Enterokinase.	Succus Entericus.	Increases the power of the pancreatic ferments, especially the proteolytic, by converting trypsinogen into trypsin.
Arginase.	Arginase.	Liver.	Converts arginin into ornothin and urea.

hunger and thirst is not known. In all cases, it is acknowledged that thirst is more painful than hunger, and it is more urgent to satisfy thirst than hunger. A dog without food, but supplied with water, lives twice as long as a dog deprived of both food and water.

Pharmacological.

Potassium chlorate is excreted in the saliva.

Fat and bismuth restrain the flow of gastric juice.

Morphia stops the movements of the stomach and food remains there a long time.

Sulphur produces peristalsis by the development of sulphuretted hydrogen, which acts as a chemical stimulant.

Emetine of ipecac acts directly on the vomiting center, and also on the vagus nerve-ends in the stomach.

Tea is not favorable to digestion, as it retards the action of ptyalin. In the majority of cases of dyspepsia ptyalin is diminished.

In emotions, when the mouth becomes dry, it is caused by a psychical effect on the sympathetic.

The acid of the gastric juice seems to have but little control over the prevention of putrefaction, hence the diarrhœa of achylia is not due to an increase of putrefactive changes. Cold drinks are apt to escape from the stomach not thoroughly warmed, and may be a cause of diarrhœa.

After the age of fifty, Seidelin states that 40 per cent. have little or no HCL.

When more hydrochloric acid is required it is obtained by augmenting the whole quantity of gastric juice, which is pretty constant in its chemical contents, and not by pouring out a more acid juice.

Colic can be caused by a want of co-ordination in peristalsis, where a relaxation in front fails to coincide with a contraction behind.

CHAPTER IV.

ABSORPTION.

According to some authors, the absorption of the economy in its entirety consists of two processes, the *first* of which has for its purpose and aim the introduction into the blood-stream of fresh material, for the nutrition of the various tissues of the body. It is called absorption from *without,* and has its seat in the alimentary canal chiefly, aided, to some extent, by the skin and lungs. The *second* process endeavors to remove from the numerous tissues of the body, by very gradual measures, the waste-products that would otherwise accrue everywhere within the body, as a resultant of the use of its various tissues. This second process is known as the absorption that takes place from *within,* and has its seat everywhere within the tissues of the body.

For many years the old physiologists entertained the view that absorption of the end-products of digestion from the alimentary canal was purely physical; that is, that the same laws governed this bodily function that do the passage of any liquid, with its contained dissolved substances, through a dead membrane placed outside of the body. These processes of *osmosis* and *filtration,* as they were known to the physicist, are to a small extent responsible for some of the intestinal absorption. But to-day the newer view concerning this absorption is accepted, whereby it is believed that the living epithelial cells of the lining mucous membrane of the small intestine possess in themselves, as living beings, the power to exert a *selective action* during absorption; at the same time, they modify the end-products during their passage through them. They change the peptones into albumins, and unite the fatty acids to glycerin. That the process was selective, and not due to purely physical laws, was proved by the more rapid absorption of grape-sugar than sodium sulphate, though the latter was many times more diffusible than the former.

OSMOSIS.

Ions.

An electrolyte is a chemical compound which, when molten or in solution, conducts an electrical current. When such a current passes through its solution, the latter undergoes certain changes that are grouped under the name of electrolysis. The places at which the electrical current enters or leaves the electrolyte are called electrodes: the anode and cathode. The electrically charged particles, the aggregation of which constitutes a molecule of the electrolyte, are called the ions of the electrolyte. The ions which, under the influence of the electrical current, migrate to the anode are *anions;* those which wander to the cathode, *cathions.* Thus, for example, NaCl is an electrolyte; Na and Cl are its ions; Na is the cathion, Cl the anion; in the electrolysis of an NaCl solution the cathion, Na, wanders to the cathode, the anion to the anode. According to Clausius, the constituents of a greater or less number of dissolved molecules exist in a free state, and move in all directions through the solution even before the passage of an electrical current. Only the presence of the free ions makes it possible that such a solution can at all conduct electricity. If we dissolve crystals of sodium chloride in water, a part of the NaCl molecules split into ions: Na and Cl. If an electrical current is passed through such a solution the ions, which at first were moving in all directions, are arrested and drawn to the poles. An ion is the electrolytic representative of an atom.

In an aqueous solution of an acid, the kation is hydrogen, and the anion is the acid radical. In the solution of a base, the kation is the metal or metallic radical, as for example, ammonium NH_4, and the anion, the hydroxyl OH. In the solution of a salt, the kation is the metal, and the anion the acid radical. The kations carry the positive electricity, and therefore move towards the negative pole or cathode. The anions carry the negative electricity, and therefore move towards the anode. Suppose we have an aqueous solution of hydrochloric acid; the positive ion is hydrogen and the negative chlorine, the water being supposed to play no part in the conductivity. If a solution of sodium sulphate be electrolysed, the positive ion is sodium, the negative SO_4. It is convenient to have a system of names for the ions derived from acids, bases, and salts, which shall represent not so much the ions as the particles, but rather ionic substances.

The following system has been proposed, in which the names are derived directly from the names of the ionized salts. The positive ions receive their names from the positive radicals of the salts, acids, and bases by the replacement of the terminations, by the suffix ion; for example:—

Hydrion, H' Sodion, Na'
Calcion, Ca' Argention, Ag'
Ammonion, NH_4'

When one radical, as iron, Fe, exists in two sets of salts, the positive ions of these salts may be distinguished from each other by a prefix indicating electro-valency. Thus, diferrion, Fe''; triferrion, Fe'''.

The names of all negative radicals terminate in ate, ite, or ide. Corresponding to these we have the terminations for the negative ion, anion, osion, and idion, respectively. Thus we obtain:—

Sulphanion, SO_4''
Sulphidion, S''
Carbonion, CO_3''
Sulphosion, SO_3''
Hydrosulphidion, HS'
Hydroxion, OH'

The function of ions, by their presence in definite proportion in each tissue, is to preserve the "labile equilibrium" of the colloid materials of the protoplasm on which its activities depend.

Osmotic Pressure.

If over a layer of distilled water we drop a layer of colored solution like copper sulphate, then the two solutions are sharply separated from each other. But soon the line of separation between the liquids vanishes; the colorless layer of water always becomes smaller and at last disappears, so that the whole mass is colored. As soon as the color-solution comes into contact with the water, then the molecules of the salt begin to wander in the water and color it. By a certain force the molecules overcome the heavy colored particles and from beneath are moved upward, and this continues until both fluids have the same concentration.

Diffusion.—When two miscible crystallized solutions of different concentration are placed on either side of a perfectly permeable membrane, it will be found after some time that both solutions have the same concentration. If on one side of the membrane there was a 20-per-cent. solution of NaCl and on the other side a 10-per-cent. solution of NaCl, then after a time both will be a 15-per-cent. solution, because of the exchange of water and salt on each side of the membrane. Diffusion, or dialysis, is the passage of the molecules of the substances in solution.

Osmosis.—If now we separate these two solutions, a colored beneath and the water above, by a partition which can be penetrated by the water but not by the colored particles, then the partition will be pressed upward. If the partition is weighted so that its pressing upward movement does not take place, then the weight corresponds to the pressure exerted by the particles of the colored salt. The pressure measure that way is called the osmotic pressure of the solution, from the Greek to force through. Osmosis is the passage of a stream of water-molecules through a membrane.

Osmotic Pressure.[1]

Saw a Pasteur-Chamberland filter in half. The cylinder is then dipped in dilute hydrochloric acid, which is sucked through the wall of the cylinder by a hydraulic airpump in order to remove any caolin dust that might choke its pores; then rinse with water in a similar way. A beaker is now filled with a solution of potassium ferrocyanide (139 grams per liter), the cylinder is dipped into it, and the solution is sucked through its wall. After the cylinder has been again rinsed in water, it is dipped into a second beaker containing a copper solution (249 grams of the salt per liter), the inside of the cylinder being also filled with the solution. A layer of the cylinder, and this precipitate constitutes the semipermeable precipitation membrane which is permeable for water, but impermeable for salts.

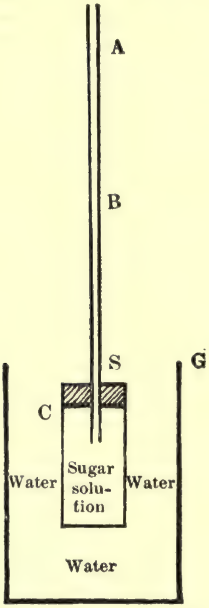

Fig. 38.—Osmometer. (COHEN.)

If we introduce a sugar solution into cell *C* prepared in this manner and close it with the stopper of rubber *S*, which is perforated by the tube *AB*, then when *C* is dipped into pure water, the sugar endeavors to pass from the place of higher concentration (the solution) to that of lower concentration (the water without the cell). But this movement is opposed by the semipermeable membrane, and in consequence the sugar exerts a pressure upon the membrane. Since this wall, however, is unyielding and so resists the pressure, a pull is exerted upon the water by the solution which tends to dilute the latter. This comes to pass when the solution enters the tube and the water from *G* streams through the membrane into the cell and dilutes the solution. This process goes on until the resulting hydrostatic pressure in *AB* prevents the further entrance of the water. When equilibrium has been established this hydrostatic pressure is equal to the osmotic pressure of the solution. Conversely, however, the latter may be measured by ascertaining the hydrostatic pressure which exists when equilibrium is established; with 100 grams of water, containing 6 grams of sugar, the osmotic pressure was 3075 millimeters of mercury.

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[1] Literature consulted: Cohen's "Physical Chemistry," 1903.

Boyle-Van't Hoff Law.—At constant temperature the osmotic pressure of dilute solutions is proportional to the concentration of the dissolved substance. Gay-Lussac-Van't Hoff law for dilute solutions is as follows: At constant volume the osmotic pressure of dilute solutions increases as the temperature; or, also, the osmotic pressure of dilute solutions is proportional to the absolute temperature.

Law of Avogadro-Van't Hoff.—At the same osmotic pressure and the same temperature equal volumes of dilute solutions contain the same number of molecules. The gases have been shown long ago to have the same laws. Although osmotic pressure can be obtained by the Pasteur-Chamberland cell with a deposit of copper ferrocyanide in its pores, yet this determination is inaccurate; hence we have recourse to the determination of the freezing point.

According to Arrhenius, the dissociated ions of an electrolyte in solution are capable of exciting pressure as well as the undissociated molecules.

It has long been known that the freezing-point of water is lowered by the addition of soluble substances. The lowering is, within certain limits, proportional to the concentration of the solution.

For the biologist the great importance of the freezing-point determination lies in the fact that it enables him to ascertain the number of molecules dissolved in a given volume of any body fluid. A depression of the freezing-point of $\frac{1}{1000}$ degree corresponds to an osmotic pressure equal to 0.012 atmospheres. While chemical analysis can tell us much concerning the composition of physiological fluids, it cannot yield us anything definite concerning the osmotic behavoir of such solutions. This becomes intelligible when we remember that the osmotic pressure of a solution is dependent upon the number of molecules (+ ions) it contains, and that this cannot be determined by chemical analysis. By the determination of the lowering of the freezing-point (cryoscopy) we have a direct means of accomplishing our end. By finding out the freezing-point of blood and of urine it is possible to discover a lessened permeability of the kidneys for dissolved molecules and disturbances in the secretion of water.

The freezing-point is determined by Beckman's differential thermometer. This, the freezing-point of blood-serum of mammals is 0.56° C. lower than water. It is usually expressed by the

Greek delta Δ. A solution of NaCl of 0.95-per-cent. strength gives the same Δ, hence the two solutions have the same osmotic pressure and 0.95 per cent. of NaCl is isotonic with mammal's serum.

The Δ of any given solution may be expressed in terms of a gram-molecular solution by dividing it by the constant 1.87, since a gram-molecular solution of a nonelectrolyte is known to lower the freezing-point 1.87° C. Now, blood-serum gives Δ 0.56° C.; then its concentration in terms of a gram-molecular solution will be $\frac{0.56}{.187}$ or 0.3. Hence blood-serum has 0.3 of the osmotic pressure exerted by a gram-molecular solution of a nonelectrolyte—that is, $22.32 \times 0.3 = 6.696$ atmospheres.

A molecule in solution exerts an osmotic pressure that is exactly equal to the gas pressure exerted by a gas molecule moving in the same space and at the same temperature. Hence the osmotic pressure of a gram-molecular solution of any substance that is not an electrolyte is equal to the gas pressure of 2 grams of H. when compressed to the volume of 1 liter.

A gram-molecule of H., that is, 2 grams of H. when brought to the volume of 1 liter, will exert a gas pressure equal to 22.32 liters compressed to 1 liter, that is, a pressure of 22.32 atmospheres. The pressure of an atmosphere is 760 millimeters of mercury.

Now, solutions of any substance can be made to possess the same osmotic pressure as any solution of another substance simply by changing the concentration, either increasing it, if the molecule of the substance is of large size, or decreasing it if it is of small size. Solutions which have the same osmotic pressure as blood-serum are isotonic. A solution which has a higher osmotic pressure is hypertonic, and that with a lower osmotic pressure hypotonic.

The osmotic pressure of urine has the highest isotonic coefficient of any fluid in the body, and its Δ is equal to 1.85° C.

The most important electrolytes present in blood-serum are the inorganic salts NaCl and Na_2CO_3.

The freezing-point of defibrinated blood is the same as that of serum; in other words, the presence of blood-corpuscles has no effect upon the freezing-point. This ensues because proteids have an exceedingly low osmotic pressure, although a high molecular weight. The freezing-point of blood does not change during hæmorrhage.

The osmotic pressure of the lymph is somewhat greater than that of the blood. An excess of carbon dioxide in the blood elevates the osmotic pressure.

In metabolism the large proteid molecules, which in solution exert an exceedingly low osmotic pressure are split into smaller ones. In consequence, the number of dissolved molecules in the tissue fluids and in the blood is increased, which causes an increase in the depression of the freezing-point of these fluids. The loss of water by the body, through evaporation, has a similar effect. It is the function of the kidneys to rid the body of this excessive number of molecules, and so keep the osmotic pressure of the blood and of the other fluids constant. If the activity of the kidneys is decreased, the depression of the freezing-point of the blood will become greater. A beginning renal insufficiency will therefore be manifested by an abnormally great depression of the freezing-point of the blood. The work done by the secretory cells of the kidneys in secreting the urine, the osmotic pressure of which is much higher than that of the blood, can be calculated by utilizing the laws of osmotic pressure. If the kidneys secrete 200 cubic centimeters of urine, the energy required amounts to 37 kilo-grammeters; that is, the energy required is equal to that expended in raising a weight of 37 kilograms to the height of 1 meter. The freezing-point of a solution of any substance in water is lower than that of the water alone. The kidney-cells separate urine from the blood against a pressure of a force about six times greater than the maximum force of muscle. The molecular weight of a body can be determined by the depression of the freezing-point.

Another theory has been proposed to explain the low freezing-point of urine. Ludwig proved that the glomerulus filters a nearly pure solution of sodium chloride, and that in the urinary tubules the water is in part reabsorbed. The theory of Koranyi is that in the urinary tubules there is a molecular exchange in such a manner that, for each molecule of urinary constituents coming from the blood, there is a molecule of sodium chloride passing from the tubules into the blood.

Loeb has shown that rhythmical contractions can be produced at will in striped muscles of the frog by *a single* salt in solution. This is not produced by the salt itself, but the ions, because it occurs only in solutions of electrolytes; that is, substances which dissociate. Among the ions found in the blood, he thinks those of sodium are the producers of rhythmical activity. Pure sodium chloride he regards as a poison. If rhythmical activity begun by it is to persist, these poisonous properties must be neutralized by calcium salts. Loeb thinks calcium and potassium salts prevent rhythmical activity, but that they, in conjunction with sodium chloride, bring about a sustained rhythm. He believes the sodium ion acts by migrating into the muscle-substance and combining with some part of it. Hence, when too many sodium ions have combined and taken the place of a number of calcium ions in the muscle, rhythmical beats cease. The poisonous effects of Na ions are antagonized by the addition of a small amount of Ca and K ions. Muscles contract only as long as they contain all three classes of ions (Na, Ca, and K) in a certain proportion, which may vary to a certain extent.

Numerous substances have been classified on the basis of the degree which they possess of passing through a membrane while in aqueous solution. Those which pass through freely have been found to be capable of crystallization, as a rule, so are termed *crystalloids;* those which are more tardy in their osmosis through a separating membrane have been ascertained to be noncrystallizable, but gluelike in nature, hence are known as *colloids.* The colloids are very feeble in all chemical relations, the reverse being true of the crystalloids. Examples of colloids are seen in albumins, gelatin, and starch, while alcohol, sugar, and ordinary saline substances form good examples of crystalloids.

Osmotic Pressure of Proteids.—It is supposed that proteids in solution exert little or no osmotic pressure. The blood contains about 6 per cent. of proteids. Starling, however, believes the proteids do exert a small osmotic pressure equal to about 30 millimeters of mercury. By reason of the want of this osmotic power the albumins and globulins remain in the blood.

Gram-molecular or Mol. Solution.—A gram-molecule of any substance is the quantity in grams of that substance equal to its molecular weight. A gram-molecular solution of any substance is the quantity of grams of that substance equal to its molecular weight. A gram-molecular solution is one which contains a gram molecule of the substance per liter. Thus, 58.5 grams of sodium chloride ($Na = 23.05$, $Cl = 35.45$) in a liter is a gram-molecular solution of sodium chloride.

Physiological Application.—The tissues are composed of cells which are small osmotic sacs, whilst the liquids surrounding them in which the phenomena of metabolism are carried on are always very dilute electrolytes. The ions and water can, as a rule, travel in both directions through the wall or protoplasmic layer of the cell. But not all kinds of substances from the lymph can travel through the cell-wall, for it has a power of selection of chemical materials from which to build itself up. Hence its nutritional changes are not wholly osmotic. However, the life of all cells is greatly dependent upon osmosis, for it must also transfer its waste products from its interior to the lymph. The life of the red-corpuscles is dependent upon osmotic pressure.

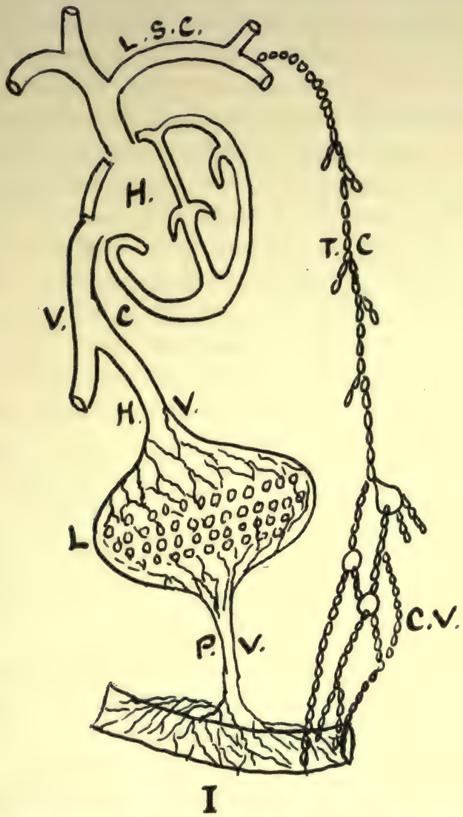


Fig. 38a.—Schema Showing the Routes by which the Digested Foods Reach the Blood. (MORAT.)

CV, Chyle vessels. *TC*, Thoracic duct. *PV*, Portal vein. *HV*, Hepatic vein. *VC*, Vena cava. *H*, Heart. *LSC*, Left subclavian vein. *L*, Liver. *I*, Intestine.

The production of lymph, the absorption of water, glucoses, and peptone from the intestine, the exchanges between the cells of the tissues and the blood and the lymph in the formation of the secretion, all require an explanation. In all these, osmotic pressure plays a part. When salt or glucose is injected into the blood-vessels, the first effect will be a stream of water from the cells of the tissues to the blood, and the production of an excess of water in the blood-stream. But soon the salt or glucose passes out into the tissues outside the blood-vessels, and then they draw the water from the blood-stream. In nutrition, the cells of the tissues use up the materials which are supplied by the extra-cellular lymph. By the concentration the extra-cellular lymph is lowered and a stream of material is set up from the blood to the cells outside the blood-vessel. At the same time, the cells of the tissues are undergoing metabolic changes, the proteid molecule is breaking up into simple molecules of the character of crystalloids, such as urea, phosphates, and sulphates, which pass into the extra-cellular lymph, increase its molecular concentration, and by their greater osmotic pressure draw water from the blood to the lymph; thus they increase the production of lymph. But as the broken-down materials from the proteids accumulate in the lymph, increasing its molecular concentration, so that it is greater than that of the same substances in the blood, then they will diffuse toward the blood, and pass out in the excretions. In absorption from the intestine, it is found that the living cells of the intestinal wall modify absorption, so that it does not follow the law of diffusion through a dead membrane.

In the pathological condition known as dropsy, there is presented a partial example of filtration. It is characterized by a transudation of the watery portion of the blood through the membranous walls of the capillaries and small veins into the surrounding connective tissues, producing œdema. This watery element has been literally squeezed through the vessel-walls.

Loeb explains this œdema by a greater osmotic pressure in the tissues than in the blood or lymph. Chemical changes in the muscle take place which increase the osmotic pressure. These chemical conditions are the result of a diminished supply of oxygen caused by deficient circulation.

Absorption by the Stomach and the Intestines.

The stomach does not absorb water, but alcohol. Water and the salts dissolved in it are absorbed throughout the small intestine, from the pylorus to the ileo-cæcal valve, and partly by the large intestine. So that the watery chyme leaving the stomach becomes gradually thicker as it travels down the intestines. The relatively rapid absorption of water by the intestines removes from the putrefactive bacteria one of the most important conditions for their life, and inhibits their activity. Three to five quarts of water daily can be absorbed; but the fæces become thin or paplike. The jejunum absorbs better than the ileum. The dilute solutions of salts are more easily absorbed than the concentrated solutions. When colored solutions were placed in the intestines, it was found that they passed through the epithelial cells and through the intercellular spaces.

The absorption of water and salts from the intestines does not follow the laws of osmosis. If you destroy the epithelium with sodium fluoride, then absorption takes place only according to the laws of osmosis. When the epithelium is injured, there is a diffusion-stream from the blood, through the intestinal wall, into the intestinal cavity; it seems to be through the intestinal epithelium. Intestinal absorption depends upon imbibition, intestinal pressure, and diffusion. The intestinal pressure is increased by the respiratory movements, by peristalsis, and by the weight of the intestines.

The water and its salts in solution go into the blood-vessels of the villi because they are immediately beneath the basement membrane of the villus, whilst the chyle-vessel is separated from the capillaries by the stroma of the villus. The duodenum is the principal seat of absorption of the iron salts, the spleen their storage-house, and the colon their place of excretion.

Carbohydrates.

The carbohydrates are absorbed in the intestine up to 500 grams per day. The monosaccharides, dextrose, lævulose, and galactose, are absorbed as such; whilst the disaccharides, cane-sugar and milk-sugar, are first inverted into dextrose, lævulose, and galactose, the latter formed by the action of inverting ferments on lactose. The chief quantity of the carbohydrates in the food is the polysaccharides, and of these starch is a prominent one. Starch is not soluble in either hot or cold water. Its cellulose coat must be removed by cooking and baking, and still it is not fitted for absorption; it must be acted upon by the diastasic ferments of the saliva and pancreatic juice, being hydrolyzed by them, forming first soluble starch, then dextrin, isomaltose, maltose, and a little glucose. The starch remains but a short time in the mouth, and in the stomach the ptyalin acts but a short time, because the free HCl stops its activity; hence the amylopsin is the chief agent in the change of starch into maltose. Here the isomaltose is changed into maltose, and the maltose into dextrose and lævulose. You do not find maltose in the blood, notwithstanding large doses of it by the mouth, but glucose. The carbohydrates not absorbed in the intestine, by the action of bacteria undergo acid fermentation, forming acetic, lactic, butyric, carbonic acids and hydrogen gas. Large quantities of cane-sugar and milk-sugar generate acids which excite peristalsis and cause a secretion of intestinal juice, which produces a diarrhœa of frequent acid stools with a sour odor. The absorption of sugar does not follow the laws of osmosis, but the columnar cells of the epithelium must exert a peculiar activity, which temporarily may be called vital, until we can explain it. If the blood is swimming with sugar, then the kidneys secrete it, forming alimentary glycosuria. If more sugar arrives in the liver than its cells can take up and change into glycogen, then the excess from the portal vein goes into the hepatic vein and into the general circulation; and as the muscles cannot localize and use it, it must pass out through the kidneys. This is the assimilation limit for the various carbohydrates, and it is different for the same individual. The assimilation limit is higher for glucose and lower for milk-sugar. The blood-vessels in the villi are the places of absorption of the carbohydrates; that is, the portal vein.

Proteids.

Albumins can be absorbed without being changed into proteoses and peptones. Injections of soluble proteids into the vein are assimilated, and they do not appear in the urine nor increase the urinary nitrogen. Yet proteids are not absorbed as such in the process of digestion, but are changed into albumoses and peptones. Proteids were not absorbed by the lymph, for when about 100 grams of proteid were eaten by a man, the lymph escaping by a fistula was not increased in quantity, nor the amount of albumin in it augmented. Although proteoses and peptones are absorbed by the portal vein, they cannot be found in the blood. It might be supposed that the liver changes them, but peptone injected into the portal vein passes through the liver as such, lowers the blood-pressure, and acts as a narcotic. Nor are the albumoses found in the lymph-channels of the intestine. Albumoses injected into the circulation reduce the coagulability of the blood, lower the arterial tension, and act like a poison. They are quickly excreted as such in the urine.

Since during absorption of albumoses and peptones similar toxic symptoms do not appear, it must be inferred that they are changed in the wall of the intestine. Here it is again the epithelium of the intestine that changes the peptone into serum-albumin and serum-globulin. The digestion of proteid is chiefly accomplished by the trypsin; removal of the pancreas confirms this. In a mixed diet of milk, meat, eggs, butter, and bread, about 90 per cent. is absorbed.

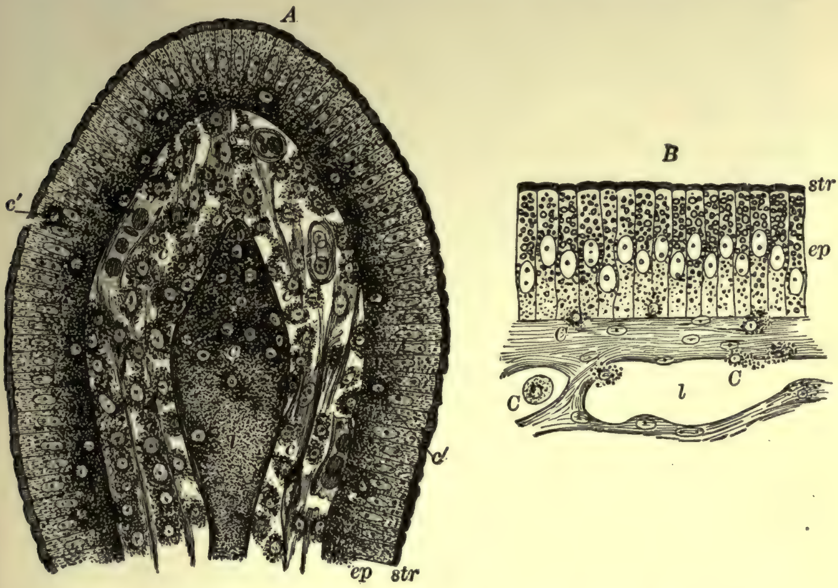


Fig. 39.—*A*, Section of Villus of Rat killed during Fat Absorption. (Schäfer.) (From Mill's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

ep, Epithelium. *str*, Striated border. *c*, Lymph-cells. *c′*, Lymph-cells in epithelium. *l*, Central lacteal containing disintegrating corpuscles.

B, Mucous Membrane of Frog's Intestine during Fat absorption. (Schäfer.)

ep, Epithelium. *str*, Striated border. *C*, Lymph-corpuscles. *l*, Lacteal.

Absorption of Fats.

Whilst the stomach has a ferment which can split up a small part of emulsionized fat into fatty acid and glycerin, in steapsin we have a ferment which splits up the fats into fatty acids and glycerin. The gall intensifies this action of steapsin. Besides, we have sodium-soap from the presence of that alkali in the gall, pancreatic, and intestinal juice. Now, the soap and fatty acids are absorbed by the epithelium of the villus. It has been shown that the fatty acids in the epithelial cell are united with glycerin to make neutral fats to enter the lacteal. Since the soaps are soluble in water, they can enter the portal circulation and be deposited in the liver, but the epithelium of the villus chiefly unites the fatty acid part of the soap to glycerin to form neutral fat, whilst the alkali is excreted into the intestinal canal, to again form more soaps.

The fats pass between the capillaries beneath the basement membrane of the villus and enter the lacteal, so that chyle has the finest emulsionized fat. About 60 per cent. of the fat ingested is absorbed by the lacteals. Bernard found in the rabbit that the bile-duct opened into the small intestine 30 centimeters above the opening of the pancreatic duct, and that the chyle-vessels did not show any fat above the opening of the pancreatic duct. Dastre bound the bile-duct in a dog and planted the gall-bladder so that it emptied into the middle of the small intestine. Then the pancreatic juice emptied above the entrance of the bile, but no chyle was visible until below the entrance of the bile. So that bile plays an important part in the absorption of fat.

Bile and pancreatic juice united are the best agency to promote the absorption of fat.

Harley extirpated the large intestine and attached the lower end of the ileum to the rectum in the dog. The fæces contained five times more water than usual, whilst the fats and carbohydrates were just as those in the normal dog. The absorption of fats and carbohydrates was as usual. The absorption of albumin was reduced to 84 per cent., compared with 95 per cent. in the normal dog. The absorption by the small intestine of salts, carbohydrates, peptones, and fats was originally supposed to be wholly due to osmosis, but now it is held to be a function of the cylindrical epithelium; for the destruction of it by the fluorides permits osmosis alone to be active as in a dead membrane, and the sodium chloride leaves the blood to enter the intestine, whilst with normal epithelium it goes from the intestine into the blood. This function of the epithelium we will, only temporarily, call vital until we can explain it.

The epithelium of the villus also, during the act of absorption, transforms the peptones into albumin and globulin of the blood, and unites the fatty acids to the glycerin to form the neutral fats of the chyle.

Rapidity of Absorption.—The rapidity of absorption has been determined by experiment. Thus it was found that lithium chloride may be diffused throughout all of the vascular structures and even into some of the nonvascular ones, as the cartilage of the hip-joint and aqueous humor of the eye, within a quarter of an hour after having been given on an empty stomach. When lithium carbonate is taken in 5- or 10-grain doses, its presence may be detected in the urine within five or ten minutes; the time for appearance is doubled, or even trebled, when the substance is taken on a full stomach.

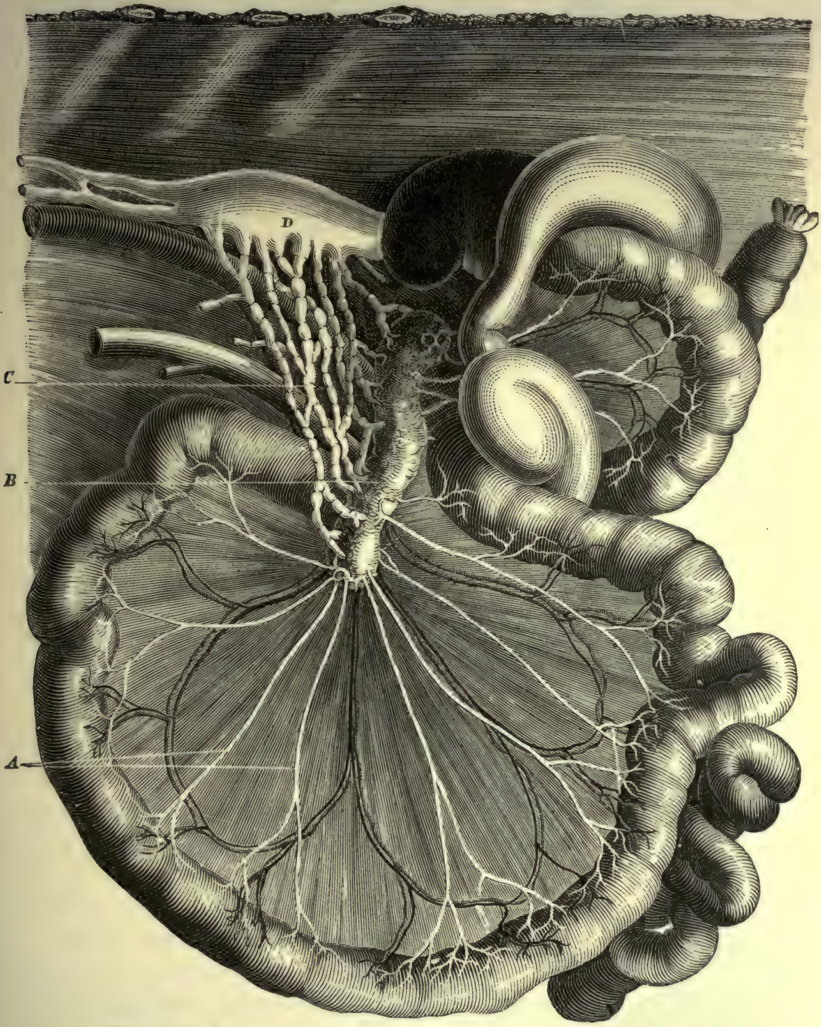


Fig. 40.—Lacteals of a Dog during Digestion. (Colin.)

A, Lacteals of mesentery. *B*, Mesenteric glands. *C*, Efferent chyle-ducts. *D*, Receptaculum chyli.

It is interesting as well as curious, to note that some of the mineral and vegetable poisons are more readily absorbed from the rectum than the stomach. Thus, it has been ascertained that strychnine in solution will produce toxic effects very much sooner when injected into the rectum than when administered by the stomach. When administered in solid form the reverse is true.

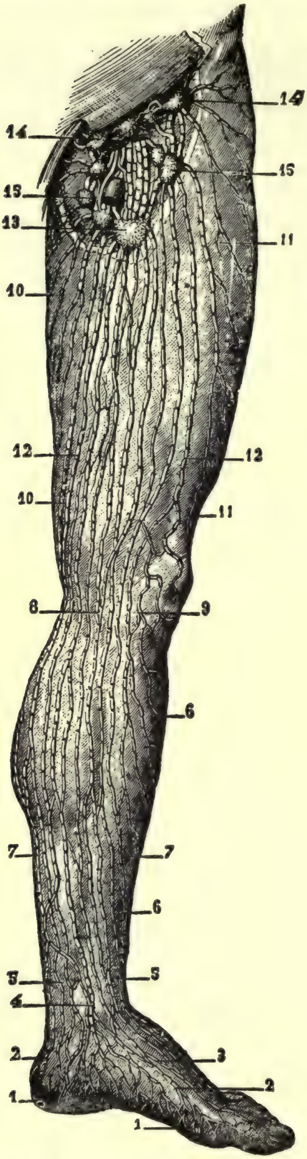


Fig. 41.—The Superficial Lymphatics of the Internal Surface of the Lower Limb. (Sappey.)

THE LYMPHATIC SYSTEM.

Having previously dwelt upon absorption as it occurs in the alimentary tract, it remains to turn our attention to the next important process in the general absorption of the body. It is the absorption from *within* as accomplished by the lymphatic system. By it as an instrument those materials of the alimentary end-products that were not taken up by the villi are collected and transported back into the regular blood-stream, while, on the other hand, fluid which has escaped from the blood-vessels and has not been used by the tissues is gathered up and again carried back into the blood-stream. Very frequently this fluid gathered from the tissues of the body after it has given up much of its nutriment to the tissues contains numerous bacteria, pathogenic and otherwise, as well as particles of waste-matter from the tissues. These are normally destroyed by the lymphocytes; if the foreign particles are too numerous for immediate destruction, they are stored up in the lymphatic glands, or, more properly, nodes, until the lymphocytes are able to dispose of them.

The watery fluid which transudes from the vessels, particularly the capillaries, is known as the *lymph.* It is this fluid which bathes every cell of all the tissues to give them nutriment, while it carries away from these same tissues the products of their activity.

Lymphatic Vessels.

In order to nourish the tissues of the body, the plasma of the blood is constantly being osmosed through the capillary walls into spaces between the cells of the tissues. Each cell is thus bathed in a plentiful supply of plasma, from which it absorbs what is needed for its nourishment. This escaped blood-plasma, together with some white cells which have found their way into the spaces, constitute the *lymph.* To prevent œdema from its accumulation, as well as to have it with its contained impurities reach the blood, from which it may be excreted, Nature makes use of a set of tubes, the *lymphatics.*

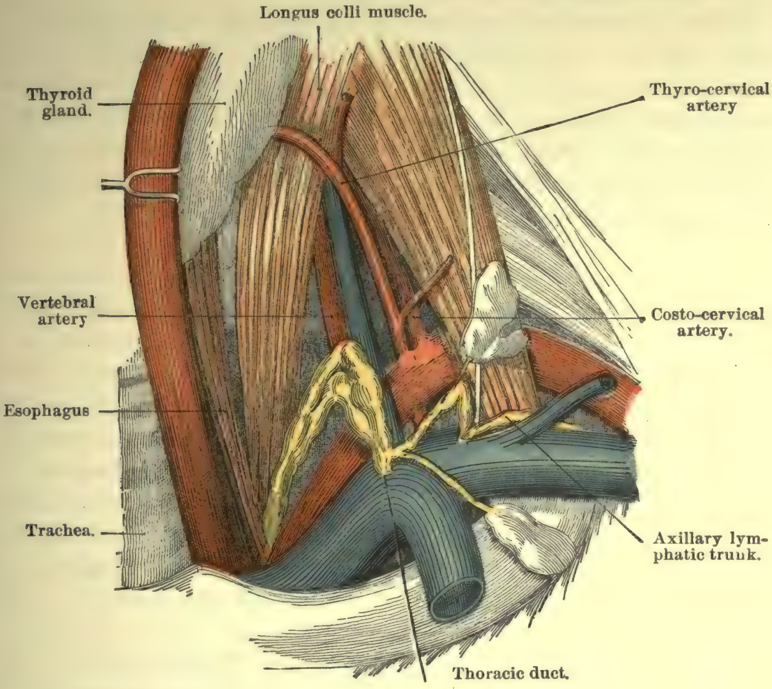

Longus colli muscle.
Thyroid gland.
Thyro-cervical artery
Vertebral artery
Costo-cervical artery.
Esophagus
Trachea.
Axillary lymphatic trunk.
Thoracic duct.

Fig. 42.—Topography of the Thoracic Duct (Zuckerkandl.) (Raymond.)

These vessels are found within the body generally, even in those structures which contain no blood-vessels, as the cornea of the eye. The fluid within them always moves in one direction only: toward the heart. These vessels, whose sources may be very different, unite in their course to form larger vessels until, by continual union, they terminate in two large trunks which empty into the subclavian veins at their junction with the internal jugulars. The one emptying into the left side is the *thoracic duct,* that into the right side is the *right lymphatic trunk.*

The large intestine possesses more lymphatics than the small, so that richness of lymphatics in a given organ is not directly proportionate to its absorbent functions. The number of lymphatics has no constant relation to the elaboration of products secreted and excreted by the glands, for they are numerous in the mammæ and liver, more scanty in the kidney, pancreas and thyroid, whilst they are abundant in the center of the diaphragm.

Structure of the Lymphatics.

When the agriculturist wishes to drain his wet lowlands he resorts to the use of pipes of great porosity. These are buried and so arranged that the moisture of the soil very readily finds its way into pipes, to flow along them and so be conveyed away. When the arrangement of the pipes is suitable, the excess of water is carried off. Should the drain-pipes become defective, or should their capacity be less than that demanded of them, there at once results a stagnation with inundation of the land. For the water to find its way from between the particles of earth and sand into the pipes it is necessary that the latter be very porous and permeable—a most essential factor.

The principle underlying the structure of the lymphatics is very similar to that of the system of drain-pipes of the agriculturist—namely: *porosity*—for the aim of each is to collect the excess of their respective fluids and convey the same to certain desired channels.

The lymphatics drain off from the system of the interstitial spaces such substances, either foreign, or useless, or harmful to the tissues, and deposit them in the lymphatic glands or carry them into the blood to be rebuilt or excreted.

This principle being kept in mind, the student can readily conceive the nature of the lymphatics.

They must be vessels of thin walls—walls which allow of the easy osmosis of plasma through them. In fact, the lymphatic vessel-walls are similar in structure to those of the veins, differing mainly in the fact that the former are thinner. Like the larger veins, the larger lymphatics consist of three coats. The inner consists of endothelium (tunica intima), the middle coat contains some muscular fibers (tunica media), while the external coat is connective tissue (tunica adventitia).

Lymphatic Capillaries.—The walls of the lymphatic capillaries simply consist of a layer of endothelial cells applied directly to a connective-tissue framework. In section, the endothelial cells are more prominent and more turgid than those of the blood-vessels. Their nuclei project into the vascular cavity, which appears as though lined by a row of little pearls. Their nuclei are oval. The lymphatic capillaries are more easily stained than the blood-capillaries by silver nitrate. When so stained they appear marked out by black lines, which, like the sutures of bone, are sinuous. It is usual to compare the borders of these cells to an oak-leaf. The diameter of the lymphatic capillaries is much larger than that of the blood-capillaries.

So thin and translucent are the walls of the capillaries, that the clear lymph contained in them can be clearly defined.

Like some veins, the larger lymphatics contain *valves* of a fibrous nature lined with endothelium. In form, structure, and attachments they are identical with those of the veins. Usually two valves of equal size are found opposite one another; these, by their functions, prevent reflux of the lymph when pressure or other disturbance is brought to bear upon their course.

Where Nature has vessels with thin walls and which vessels contain fluids propelled by very weak *vis a tergo,* she must needs resort to numerous valves. So numerous are these little safeguards that when the lymphatics are injected they present the appearance of a string of beads.

While dealing with lymphatics, mention must be made of those modified lymphatics known from ancient times as the *lacteals.* These vessels take their origin from the intestines to empty their contents via the thoracic duct into the left subclavian vein for admixture with the systemic blood. The lacteals were so named from their white color at certain times; that is, during active digestion, when the lymph-stream is overwhelmed by the absorbed fatty granules, which give to it its milky hue. The milky-colored fluid has been termed chyle.

During the intermission between active digestion the lacteals carry pure lymph, and, from their functions and structure being identical with that of true lymphatics, they deserve to be classed with the latter.

Origin of the Lymphatics.

Lymphatic System.

Miss Florence R. Sabin has shown that the lymphatic system in the embryo pig develops as two blind diverticula from the veins of the cervical and inguinal regions. These grow toward the skin and widen out into four lymph-sacs, from which the final lymphatics proceed. By a special growth of the lymphatics along the dorsal line, the thoracic duct is formed.

Though many features of this system are yet obscure and open for investigation, it seems very probable that, as stated by Landois, the lymphatics arise as follows:—

1. **Connective-tissue Spaces.**—These are very numerous, star-shaped or irregularly branched spaces which communicate with one another by fine tubular processes. They are lined with endothelium and contain lymph and a few "wandering cells."

2. **Within the Villi.**

3. **In Perivascular Spaces.**—The small blood-vessels which supply bone, central nervous tissue, retina, and the liver are themselves surrounded by lymphatic tubes which, in many instances, are larger than the blood-vessels. Between these tubes and the blood-vessels there exists a space called the *perivascular space* of His. These are believed to be one source of lymphatics, for, when they exist, the passage of lymph-corpuscles into the lymphatic vessels is greatly facilitated.

4. **In the Form of Interstitial Slits Within Organs.**—Within the testicle and certain other organs there exist long, slitlike spaces between the various cells and network of tubules. They are all, however, lined with endothelium. Into these spaces there is poured lymph from the blood-capillaries for the maintenance of the glandular cells, and at the same time it furnishes material for secretion. From these little slits lymphatics take their origin, but receive independent walls after their exit from the gland-substance.

5. **By Means of Free Stomata.**—These occur, for the most part, upon the walls of the larger serous cavities. Lymph is pumped here by the alternate dilatation and contraction of the serous surface, due

to the movements of respiration and circulation; so that serous sacs may be regarded in a certain sense as large lymph-cavities. Fluids placed within these cavities readily find their way into the lymphatics. The cavities referred to are those of the peritoneum, pleura, pericardium, aqueous chamber of the eye, and labyrinth of the ear.

6. In the mucous membrane of the nose, larynx, trachea, and bronchi there have been noticed **open pores** which are in communication with the lymphatics.

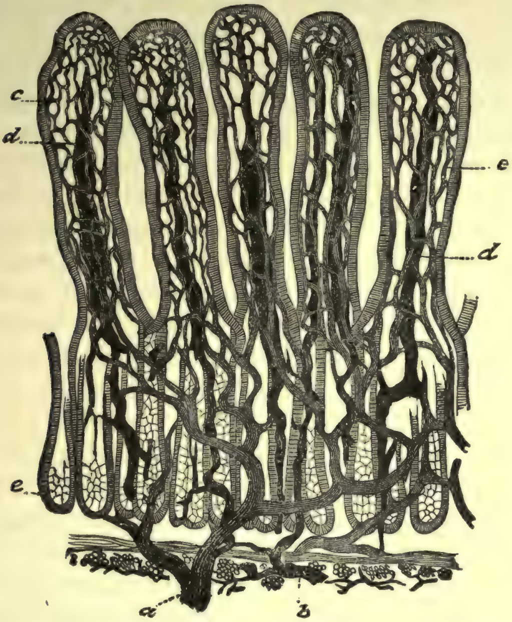


Fig. 43.—Section of Dog's Intestine, showing Villi. (CADIAT.)

c, Blood-vessels, injected. *d*, Lacteals, injected. Blind end of villi enveloped in a capillary network of blood-vessels.

Lymphatic vessels of moderate size are supplied with nutrient vessels (vasa vasorum), which are distributed to the external and middle coats of their walls; up to the present time no nerve-supply has as yet been ascertained except for the thoracic duct.

Ranvier and others state that there is no origin of lymphatics from open spaces in the tissues. They believe lymphatic capillaries are terminated by absolutely closed *culs de sac*.

Lymphatic Glands.

Lymphatic glands are shaped much like a kidney. The oblique afferent vessels approach their convex border, whereas the efferent vessels, which are larger and more numerous, escape from the hilum on their concave border. Their consistence is that of the liver, and their color varies in different regions, but usually is a rosy white. In size they vary from an olive to those invisible to the naked eye. As age advances, the glands become much smaller. Their number is 600 to 700. The glands are almost always buried in a bed of adipose connective tissue, usually united in groups of three to six, or even ten to fifteen, forming chains or chaplets. Their situation is generally paravascular and paraepithelial. A lymphatic gland consists of three parts: (1) the capsule, (2) the cortex, and (3) the medulla. The cortex is composed of a number of cells, the majority of which are small. The nucleus is rounded or quadrangular, and has a thick chromatin border; in its center are one or two chromatin granules. Sometimes, but not always, a true nucleolus is found. These elements are identical with the microcytes of blood and lymph (lymphocytes). The large cells correspond to macrocytes. The follicles of the cortex formed by the trabecula of connective tissue have no proper wall; they are limited by the endothelium of the lymphatic sinus, which surrounds them. The follicle with the clear center is essentially a seat of cellular reproduction, and it has been termed a germinitival center, a seat of karyokinesis.

The Medulla.—The medulla presents cords, irregular in size, shape, and course. These cords anastomose with each other and are separated from each other by large, clear spaces, the cavernous sinuses. The medullary cords are central prolongations from the cortex, and are formed of the same cells, which are here sometimes agglomerated. Between the cords the cavernous sinuses show us the best place for studying phagocytosis of the gland and of the reticulum. The reticulum is formed by an anastomosis of cellular prolongations. Some of the cells of the reticulum have an elongated, clear nucleus; others have distinct nuclei.

Afferent Vessels of the Lymphatic Gland.—The afferent lymphatics pass through the capsule, lose their tunica adventitia and muscular coat, and, like true capillaries, become reduced to their endothelium. By the anastomosis of their capillaries they form a vast peripheral sinus, which generally separates the capsule from the follicles. From the sinus, interfollicular branches, which reach the medullary part, run out where they run between the follicular cords, and finally throw themselves into the efferent vessels in the region of the hilum. The efferent lymphatic trunks are less numerous, but larger than the afferents. Thus the follicles and follicular cords appear as islets which are plunged into a vast portal system, which bathes them on every side. By confluence and capillarization the lymphatics form a vast pouch around the glandular substance, in which the current is slowed and the pressure lessened. In the arterial supply it is seen that the follicular cords are pierced in the center by an arteriole, just as the Malpighian corpuscles of the spleen. The arteries reach the cortical layer, surround the follicles, to which they furnish little branches which converge toward the center like the spokes of a wheel towards the axle. These glands have nerves which surround the follicles and give off finer branches reaching the center of the nodular structure, where they appear to terminate in free extremities.

Leucocytosis.—Whether the glandular cells are fixed leucocytes or derivatives of the mesodermic elements, they produce the white blood-corpuscles. The leucocytes are more numerous in the efferent than in the afferent vessel. There is a close relation between blood-leucocytosis, glandular hypertrophies, and the number of mitoses. Removal of certain important glandular groups diminishes the number of leucocytes. The gland-cells are generators of the lymphocytes, and the gland is a cytogenous gland like the testicle. The gland specially produces microcytes (lymphocytes).

Composition of the Lymph.

Lymph is a diluted blood-plasma, and is found in the lymphatic vessels, as well as in the extravascular spaces of the body. All the cells of the tissues are bathed in lymph. Whilst the generation of lymph may be held to be from the blood-plasma, yet the intravascular tension may be increased by a flow of water from the plasma into the lymph-spaces, or by a flow from the cells of the tissues into the lymph-spaces that surround them.

Lymph is an albuminous, colorless fluid, which contains lymph-corpuscles; these are identical with the colorless blood-corpuscles. Lymph is alkaline, has a specific gravity of about 1.015, and when drawn from its vessels it clots, forming a colorless coagulum of fibrin. The watery part of the lymph is known as the *lymph-plasma*, which contains the three elements necessary for coagulation: fibrinogen, fibrin-ferment, and calcium salts. It is very similar to blood-plasma.

The proteids present are *fibrinogen, serum-globulin,* and *serum-albumin.* The three proteids in the blood are diminished in the lymph, especially the fibrinogen.

The extractives in lymph are urea, fat, lecithin, cholesterin, and sugar, with the inorganic salts. The quantity of salts in the lymph and the blood is the same. The lymphocytes contain glycogen.

The apparently transparent lymph is found to contain corpuscles when examined under the microscope; to them the name *lymphocytes* has been applied. They have a large nucleus with comparatively little protoplasm. In some places—the thoracic duct, for example—a few colored blood-corpuscles are found and are believed to have found their way into this distinct system by reason of diapedesis. The regular lymphocytes find their way into the blood-stream, where they multiply and are known as leucocytes.

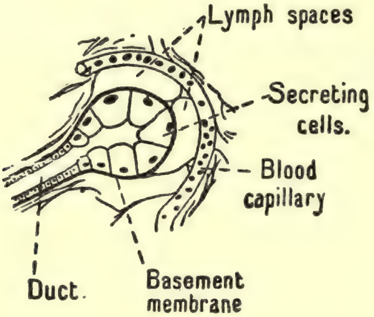


Fig. 44.—Diagram to Show Relation of the Secreting Cell of a Gland to the Blood and Lymph-supply. (Starling.)

The real manufactories of these lymphocytes are the lymphatic glands, whose alveoli contain adenoid tissue. The number of lymphocytes is much greater in the lymph after it has passed through a gland, and we find that lymph collected from regions where there are few glands, as the lower extremities, is always poorer in albumin and richer in water than the lymph in the large lymphatic vessels.

For purposes of analysis, lymph can be obtained from the limbs, thoracic duct, and serous cavities. Accidental lymphatic fistulæ in man, as well as experimental ones in animals, have been the source of much lymph for analytical purposes.

The pericardial fluid and aqueous humor are forms of lymph which are not coagulable except upon the addition of fibrin-ferment.

Cerebro-spinal fluid has the identical appearance of lymph, but differs from it in chemical properties and composition.

Synovial fluid of joints differs from true lymph in that it contains mucin or mucinlike bodies and a high percentage of solids.

Chyle is the term used to designate the fluid of the lacteal system during active digestion, particularly of fats. It is an opaque, whitish, milky fluid, neutral or slightly alkaline in reaction. The color of the chyle is due to the presence in it of numerous *fatty granules,* each surrounded by an albuminous envelope, very minute, though uniform in size. Their fatty nature becomes evident when they are treated with ether, for they are immediately dissolved. Varying quantities of the fat give different shades of whiteness to the chyle. Thus, in addition to the constituents of the lymph, the chyle contains a large amount of fat, which is its characteristic feature. During fasting the chyle in the lacteals resembles ordinary lymph.

As the chyle passes on toward the thoracic duct, especially when traversing some of the mesenteric glands, it is elaborated. As a result there are fewer fat-particles, but there now begin to appear corpuscles to which the name *chyle-corpuscles* is applied. Further, it now gains the ability to coagulate spontaneously. As the chyle advances in the thoracic duct the corpuscles become more numerous, and the larger and firmer becomes the clot when the chyle is withdrawn from its vessels. The clot is like that of blood when only white corpuscles are present. Its ability to coagulate is due to the disintegration of the lymph-corpuscles which supply it with the necessary fibrin-factors.

Flow of Lymph and Chyle.

The lymph and chyle always run in a centripetal direction from the periphery to the center under the influence of various forces. The villi contract and push their contents in a centripetal course, aided by the contractions of the intestinal muscles. The dilatation of the blood-vessels at each contraction of the heart pushes the lymph out of the perivascular spaces.

Once the lymph and chyle are in the vessels they continue to move by the muscular contraction of the walls of these vessels, and this movement can only take place in a centripetal direction by reason of the arrangement of the valves. The lymphatic ganglia, by their structure, offer a resistance to the circulation of the lymph, but their fibrous covering and unstriped muscles favor the flow.

Cold-blooded animals have lymphatic hearts which act as motors in circulating the lymph. The valves in the lymphatic vessels are powerful adjuvants in propelling the lymph in a central direction. The respiratory movements have an influence. At the time of inspiration the flow of lymph, like the blood, rushes into the chest, owing to the partial vacuum in the chest. The pressure by muscular action on the lymphatics also greatly aids in the propulsion of the lymph.

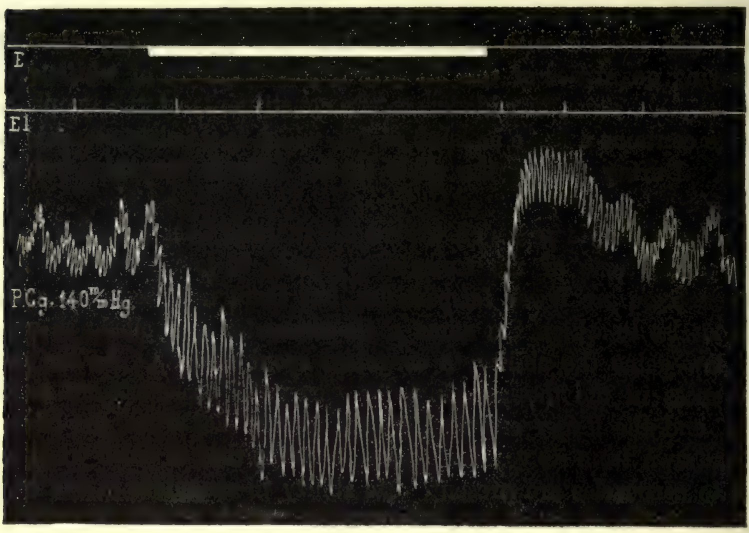


Fig. 45.—Diminution of the Flow of Lymph under the Influence of the Slowing of the Heart. Dog narcotized with morphia and chloroform. (L. Camus.)

E, Irritation of the peripheral end of left vagus. *El*, Drops of lymph from thoracic duct by the vertical lines, *P.Cg.* Pressure in left carotid equals 140 millimeters of mercury.

Lymph moves at the rate of about ten inches per minute, and its pressure is fifteen millimeters of soda solution.

The *nervous system* bears a direct relation to the lymph-stream in so far as it governs the musculature of the lymph-trunks and capsule and trabeculæ of the lymph-glands. A solution of common salt injected beneath the skin of a frog will be rapidly absorbed; but when the central nervous system is destroyed, then no absorption takes place.

Drs. Camus and Gley found in the sympathetic, below the first thoracic ganglion, nerves which contract and dilate the thoracic duct; usually the effect is one of dilatation.

Formation of Lymph.

About 1847 Ludwig and DuBois Reymond began to explain the phenomena of life by the law of physics and chemistry. Since the middle of the eighties of the last century, owing to the failure to explain several phenomena, there has arisen a school of Neovitalists, who explain the same observations as being due to vital activity. The secretion of lymph is one of these cases in point.

There are three theories which explain the secretion of lymph:—

1. Ludwig's or the Filtration Theory, which requires that the pressure be higher on one side of the membrane than on the other. The blood-pressure in the capillaries is greater than the pressure outside the capillaries in the lymph-spaces. Hence, the diluted plasma or lymph will filter through the capillaries.

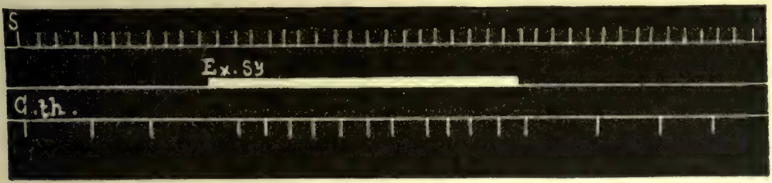


Fig. 46.—Dog with Medulla Divided. (L. CAMUS and E. GLEY.)

Ex, Irritation of the lower end of the thoracic sympathetic below the stellate ganglion. *C.th,* Drops of lymph from the thoracic duct, indicated by the vertical lines. The experimenters were very careful that during the irritation of nerve neither the carotid nor the jugular pressure was altered. Dilatation of the thoracic duct by irritation of the thoracic sympathetic, causing an acceleration of the flow of lymph.

By this exudation the interstitial pressure always tends to the same height as the intracapillary pressure—the stronger the intracapillary pressure, the stronger the interstitial pressure. On the other hand, the stronger the interstitial pressure, the more easily the lymph will be absorbed by the lymphatic capillaries. We must admit, with Ludwig's filtration theory, that the pressure of the blood is a powerful cause in the circulation of the lymph, and this can be easily shown by section and irritation of the spinal cord, after a cannula has been introduced into the thoracic duct, where the lymph-flow decreases with the dilatation of blood-vessels on section of the cord and increases on irritation of the cut section.

Ludwig also made a second factor in his theory, and that was osmotic changes between the lymph and the blood.

2. Heidenhain's Theory.—He believes filtration of the plasma, due to higher pressure in the capillaries, will not suffice to explain the formation of lymph. When glucose is injected into the blood, there is more glucose after a time in the lymph than in the blood. He calls the agents which cause an increased secretion of lymph, lymphagogues. He makes two classes of these. The first class consists of peptone, extract of leeches, and watery extract of crayfish. The second class comprises sugar, sodium chloride, urea, and salts.

The first class of lymphagogues does not increase blood-pressure or affect the circulation, hence blood-pressure could not be stated as the cause of the increased flow of lymph. He ascribes the action to a stimulation of the endothelial cells of the capillaries. After action by the first class of lymphagogues, the blood-plasma contains less organic principles than the lymph. The explanation of the action of the second class of lymphagogues is as follows: The lymph-secretion by these agents is poorer in proteids than normal lymph. Whilst the lymphagogues of the first class do not affect the urinary secretion, those of the second class increase the secretion of both lymph and urine at the same time. If injections of the second class of lymphagogues are made slowly they do not affect blood-pressure. Heidenhain explains their action in this way: the crystalloid substances within the circulation are gradually secreted into the lymph-spaces and urinary tubules by the aid of the endothelial cells of the capillaries. Then the crystalloids in the lymph-spaces, by their high osmotic power, attract water from the tissues.

3. Starling's Theory.—In the limbs the flow of the lymph is very scanty, whilst in the liver and the intestinal area it is much more abundant. Starling holds that the capillaries of the liver are most permeable, the capillaries of the intestinal wall are less permeable, and the capillaries of the extremities the least. Thus, lymph from the extremities contains only 2 to 3 per cent. of proteid, from the intestines 4 to 6 per cent. of proteid, from the liver 6 to 8 per cent. of proteid, which is nearly as much as that of blood-plasma. Starling explains the action of the lymphagogues of the first class of Heidenhain (peptone, extract of leeches, and watery extract of crayfish) by a change in the permeability of the capillary wall, as these agents are poisonous and alter the permeability of the endothelial walls of the capillaries, especially those of the liver. To account for the variation in the amount of proteids in the lymph, Starling puts forth the permeability of the capillary wall. The larger the pores in a membrane, the more permeable the membrane will be for the colloids, and the richer the filtrate will be in organic material. This explains the action of the first class of lymphagogues in producing a lymph containing more organic principles than the blood. As to the second class of lymphagogues of Heidenhain, it has been shown that the intravenous injection of sugar or sodium chloride into the circulation causes a large amount of water to leave the tissues and enter the circulation. The high osmotic pressure of the sugar or other crystalloids in the capillaries causes an attraction of water from the tissue-spaces and from the tissues themselves, and, of course, an hydræmic plethora and an increased blood-pressure, then the filtration of much lymph, and necessarily one poor in proteids. The amount of lymph produced is dependent solely on two factors: (1) the intracapillary blood-pressure (Ludwig's theory), and (2) the permeability of the endothelial wall of the capillaries of the circulation (Starling's theory).

Absorption by the Blood-vessels.

Fluids can be absorbed from the lymph-spaces and from the serous cavities into the blood. This is due to the osmotic pressure exerted by the proteids in the blood for the water in the lymph-spaces. In this way, after a severe hæmorrhage, the blood-vessels are rapidly filled by the water absorbed from the lymph-spaces. If there is an excess of fluid in the blood-vessels, part of it is excreted by the kidneys, and part of it passes into the lymph-spaces.

Quantity of Lymph and Chyle.

The free interstitial lymph comes in contact with three different elements: the tissues of the organ, the blood of the capillaries, and the lymphatics. Once the lymph is within the lymphatics, none of the fluid returns to the spaces of the tissues.

The quantity of lymph is a varying factor, due to changes in pressure in the capillaries, which, of course, will alter the rate of filtration of the blood-plasma. In digestion, the blood-plasma is charged with the proteids of digestive activity, and consequently the difference of composition between the blood and the lymph will set up osmotic pressures, tending to make each similar in composition. Further changes in the elements of the tissues, whether normal or due to disease, alter the composition of the lymph, and they also set up osmotic pressure, tending to make the blood and lymph similar in composition.

The formation of lymph in the tissues takes place continually and without interruption. The amount of lymph increases with the activity of the organ from which it proceeds, while active or even passive movements of the muscles greatly increase its amount.

It may be roughly stated that the amount of lymph and chyle combined passing through the large vessels in twenty-four hours is about 2 pounds.

Skin and Lungs.

It remains to consider the nature of the absorption that takes place through the skin and lungs. These avenues are but subsidiary ones to the two greater ones just mentioned: intestinal absorption and that along the lymphatic system. Absorption through them takes place from *without;* so that it is usually classed with the first of the two processes of absorption mentioned at the beginning of this chapter.

For a long time it was a subject for much discussion whether water was absorbed by the skin with the epidermis still intact. It was a rather difficult matter to ascertain, since the skin is constantly giving off water in the form of perspiration, sensible or insensible. The absorption of water through the skin covering the body takes place very rapidly in the lower animals. It has been finally ascertained that absorption of water *does* take place through the skin of man, but to a much less degree than in animals. Aqueous solutions of various drugs when in simple contact with the skin are only slightly active. It is believed that the great hindrance to their absorption is the presence of the fat that is normally present upon the skin and in its pores and interstices. If this be removed by the application of alcohol, ether, or chloroform, physiological effects of the drugs are soon manifested.

Inunction.—When ointments are *rubbed* into the skin absorption will take place. Mercury, when applied in this manner, exerts its specific effect upon syphilis and excites salivation; tartar emetic so applied may produce vomiting or an eruption extending over the entire body. Voit found globules of mercury between the layers of the epidermis and even in the corium of a person who had been executed and into whose skin mercurial ointment had previously been rubbed. An abraded or inflamed surface absorbs very rapidly.

Under normal conditions minute traces of O are absorbed from the air; CO, CO_2, vapor of chloroform, and ether may also be absorbed.

In dysphagia, when the condition is so severe that even fluids cannot be taken into the stomach, immersion of the patient into a bath of warm water or water and milk may quench the thirst. It is well known that sailors, when destitute of fresh water, assuage their thirst by wetting their clothing with salt water and wearing them until dry. It is very probable that the effects produced are, in a great measure, attributed to hindrance to the evaporation of water from the skin.

Through the Lungs.—It is interesting to note that not only do gases pass through the epithelium of the pulmonary air-vesicles, but that fluids, such as water, may be absorbed when they have found their way into the air-passages. The presence of particles of carbon in the bronchial glands and other tissues of the respiratory apparatus is accounted for only by reason of the open pores: one of the origins of the lymphatic system.

CHAPTER V.

THE BLOOD

Blood is a red, somewhat viscid fluid, denser than water, and apparently composed of but one substance. This liquid, which is usually spoken of as the nutritive fluid of the body, serves as an internal medium of exchange existing between the foodstuffs found in the outer world and the cells composing the various tissues of the body. It was constantly kept before the student's attention that the main and ultimate end of digestion was the absorption of the foodstuffs into the blood-stream, not as proteoses and peptones, but as native albumins and globulins—these latter are the results of the living, vital activity of the epithelial cells of the villi through which pass the proteoses and peptones. Thus, into the blood are poured new products (the work of digestion), which are carried by its circulation to all parts of the body, to be given up to the various tissues having need of them. By this means every cell receives the nutriment necessary for carrying on its own metabolic processes, either directly or indirectly, for the student will remember that each cell possesses an inherent selective capability. From the pabulum contained in the enveloping lymph it is able to take up those factors which it can work up into its own constitution to form an integral part of itself. These constituents, having served their respective purposes, are no longer of any value to the cell—they are waste-products, and as such must be gotten rid of. Passing out from the cell-substance, they find themselves in the same enveloping lymph, to be eventually carried again into the blood-stream for elimination through the excretory activities of the lungs, kidneys, and skin. Thus, indirectly the blood is a medium of elimination of such deleterious products as urea, uric acid, water, carbon dioxide, etc.

However, the afferent function of the blood is not simply single, for it conveys to the tissues in addition that material, all-important for successful combustion,—namely, oxygen,—which has been obtained from the respired air of the lungs. Among warm-blooded animals another office served by the blood is to equalize to a certain degree the temperature of the body.

Color.—There are certain characteristics which distinctly mark blood from other fluids. The color of the blood of the vertebrata is generally red. Its shade is, however, not fixed. As the blood-stream passes through a variety of tissues and is subjected to many different conditions, its color varies from a scarlet red in the arteries to a bluish red in the veins. It is the presence of the oxygen in combination with hæmoglobin that gives to the arterial blood its bright color. Lessened oxygen means excess of carbon dioxide, and it is the presence of the latter that gives to venous blood its characteristic bluish-red color.

When normal blood is drawn from a blood-vessel and placed as a very thin film upon a glass slide, it is found to be opaque, and printed matter cannot be read through it. This opacity is produced by differences of refraction possessed by its several components.

The healthy red color of the nails, conjunctiva, lips, ears, and mucous membranes in general is due to the presence of the blood. When there is insufficient supply to these parts,—temporarily in fainting or for a longer period, as in anæmia,—they become pale and waxy in color. In asphyxia and certain heart affections there is a want of proper oxidation, with a resultant bluish color to the above-named parts.

The color of the blood is changed by the action of poisons. The most marked alteration is the cherry-red color produced by the toxic action of carbon monoxide. This red color is deeper than that of arterial blood.

Reaction.—The reaction of blood is alkaline. This alkalinity is variable in amount. Thus, it is diminished after great muscular exertion, owing to the formation and presence in it of a large quantity of sarcolactic acid. After long-continued ingestion of soda the alkalinity is increased; after the use of acids it is diminished. In no case, however, does it become distinctly acid. To test the alkalinity of the blood, dry, faintly reddened glazed litmus-paper is used. Upon it is placed a drop of blood, which is allowed to remain for half a minute, to be then wiped off with a weak salt solution. The result is a blue spot upon a red background.

The alkalinity shown by titration with tartaric acid is the amount of alkali Na, in combination with weak acids, as carbonic or phosphoric, and is known as "titration alkalinity." It has been extensively studied in disease. The average alkalinity of human blood by titration with a standard acid after the corpuscles have been broken up is that of a 0.2- to 0.3-per-cent. solution of sodium hydrate. However, the true alkalinity of the blood is the number of hydroxyl ions (OH^-) free in the solution. Physical chemistry by the electrometric method has shown that blood is a liquid very nearly neutral; the concentration of the hydroxyl ions is nearly the same as in distilled water.

Freudeberg states that an ounce of dilute lactic acid in one day reduced the alkalinity of the blood one-fourth, whilst two drachms of tartaric acid diminished it one-sixth.

Blood maintains its consistency in composition by the excretion of the kidneys and exudation into the lymph spaces of tissues.

Life is incompatible with an acid blood, for an injection of an acid by the vein quickly causes coma and death, as in the acidosis of diabetes. Venous blood is less alkaline than arterial blood. Its alkalinity is chiefly due to the presence of disodic phosphate and bicarbonate of soda.

Taste.—Blood possesses a distinctly salty taste.

Specific Gravity.—The specific gravity of normal, healthy blood varies within certain limits: for men, about 1.057 to 1.066; for women, 1.054 to 1.061. Its density is influenced by various factors and conditions. If fluids be used sparingly and a dry diet eaten, the density is increased. It is also increased by exercise and profuse sweating. It falls when fluid is injected into the vessels, but for a short time only.

Temperature.—The temperature of the blood varies between 97.7° and 100° F. The cutaneous blood-supply is slightly lower in temperature, while the warmest blood is that in the hepatic vein; the coldest in the tip of the nose.

Odor.—Fresh blood imparts a decided odor, peculiar to the animal from which it is drawn. The odor of blood is due to volatile fatty acids held in solution. The effect becomes more striking upon the addition of concentrated sulphuric acid to the blood.

Viscosity.—The viscosity of the blood considerably exceeds that of the plasma, or that of the serum, and is dependent upon the number of suspended blood corpuscles.

Burton-Opitz made blood laky by repeated freezings, and found the viscosity diminished. The viscosity is increased by the increase of carbonic acid in the blood; hence venous blood has more viscosity, according to Burton-Opitz, than arterial. Burton-Opitz has shown that hunger reduces viscosity and meat diet raises it to a great height, whilst carbohydrates and fat diet give average values to it. Hürthle has found in animals and Hirsh and Beck in man that it is inversely related to the coagulation time; hence the less the viscosity the greater the time in coagulation.

High altitudes increase the viscosity of the blood. The specific gravity of the blood may be regarded as a safe index of viscosity. The greater the specific gravity the greater the viscosity. Hürthle has estimated that the work done by the heart in the dog is more than four times as great as it would be if the circulation contained distilled water instead of blood. This difference is due to the viscosity, which is 4.7 times that of water.

In cholera, the viscosity of the tarry blood is so much it will not run through the capillaries. Polycythæmia also increases the viscosity. Here the capillary circulation is slowed and the extremities are cold or dusky. Alcohol, by the digestive tract or by vein, makes the viscosity greater.

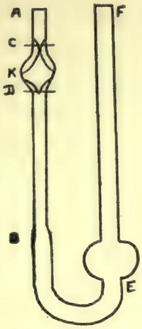


Fig. 46a.—Viscosimeter of Ostwald.

The tube is filled with a measured quantity of blood. Suction is made in the tube *A* until the blood rises up to the mark *C*. Then the blood, by its own pressure, is permitted to fall to the mark *D*. In a like manner a similar quantity of water is used. The time occupied in the fall from *C* to *D* of these fluids is compared. (ASHER.)

Quantity of Blood.—From very early times the theme of the quantity of blood circulating within the body has been uppermost in the minds of physiologists and investigators. By reason of the methods then employed the results were inaccurate and difficult of attainment. Simple bleeding was resorted to, but deductions depended upon the rapidity with which the blood was lost. If the animal was bled very rapidly, then considerable blood remained in the vessels. If the blood was extracted very slowly, not only blood, but serum from the lymphatic vessels, spaces, and glands was obtained. These factors very materially altered the calculations.

The accepted, though not very simple, method, for determination of the quantity is that of Welcker's. It is as follows: The specific gravity of the blood as well as weight of the animal are first noted. A cannula is placed in the animal's carotid through which is extracted a quantity of blood to serve as a sample. This is defibrinated, whereupon portions of it are diluted at different known strengths. The remainder of the blood in the body is then allowed to escape, and is collected and defibrinated. A normal salt solution is next run through the vessels and likewise collected. The entire body, minus the stomach and intestines, is then cut into very fine pieces and extracted with water for one or two days, at the end of which time the bloody water is expressed and added to the drawn blood and washings. The entire amount is carefully measured.

The experimenter compares this diluted blood with the previously prepared samples of the diluted blood of known strength until he finds tints of two that are exactly alike. From the total quantity of diluted blood and the knowledge of what the sample contains it is comparatively easy to calculate the amount of blood contained in the body. To this must be added the blood drawn at first to make the various samples. The weight of the animal compared with the above results gives the proportionate amount.

By this and similar computations it has been ascertained that the blood is equal to from one-eleventh to one-fourteenth of the bodyweight. Approximately, it may be said to be one-thirteenth of the bodyweight.

"Roughly, it may be said that the lungs, heart, large arteries, and veins contain one-fourth; the muscles of the skeleton one-fourth; the liver one-fourth; and other organs one-fourth." (Ranke.)

The quantity of blood is a variable quantity. It is more abundant during absorption of the digestive products than in fasting. It has been experimentally proven that during digestion the lethal dose of strychnia must be double that in an animal fasting. Diarrhœa and sweats diminish the quantity of blood. The viscera contain the most blood; the muscles contain much less. The quantity of blood in an organ varies with its activity or repose. The salivary glands when active receive four times more blood than when in repose.

Arterial and Venous Blood Compared.—At this point the student's attention is called to a few main points wherein the arterial and venous bloods differ. Very conspicuously stands out the marked difference in color: the scarlet of arterial, the bluish red of venous blood. These color-differences depend primarily upon the amount of oxygen-gas contained in the blood. It unites with the iron of the blood-corpuscles (little bodies) to form a very unstable compound, known as oxyhæmoglobin. When carbon-dioxide gas is present it also forms an unstable compound. Its color is dark. When oxyhæmoglobin is in excess, as it is in arterial blood, the color is a bright red. When carbon dioxide is in the ascendancy, the blood is bluish red in color and the oxygen-gas is present in diminished amounts.

Arterial blood contains more of the assimilable products of the digestive processes, so that it is better fitted to supply the cells with their proper nourishment. It also contains greater quantities of salts, fats, and sugars.

Venous blood contains less nutriment, but more waste-products, particularly urea and carbonic acid resulting from catabolic processes.

Composition of the Blood.—Apparently the blood-stream, as viewed by the naked eye, is composed of one homogeneous, red substance; but when examined histologically with the microscope this impression becomes entirely dispelled. It is then found to be composed in reality of a transparent liquid portion, known as the *plasma*, or *liquor sanguinis*, in which, as a medium, float an immense number of *blood-corpuscles*. The great majority of these latter are colored, and it is to them that the blood owes its color. There are at least three different kinds of blood-corpuscles, commonly known as the *red* corpuscles; the *white* corpuscles, or *leucocytes;* and the *blood-plates.*

The *red corpuscles* of mammalia—the camel and others of the group of *Camelidæ* alone being excepted—are circular plates, biconcave, and without nuclei. Those of the birds and reptiles are elliptical, biconvex and nucleated.

Human red blood-corpuscles are biconcave, disc-shaped bodies with rounded edges and slight central depressions. They have been tersely described by one author as "circular, biconcave, nonnucleated discs."

Weidenreich holds that the red corpuscles are bell-shaped and not biconcave, the latter condition being due to evaporation and concentration of blood outside the body.

The corpuscles are formed of a semisolid, homogeneous, iron-holding mass which appears to have no membrane or nucleus, for a nucleus is normally met with in them only during embryonic life of mammals and in the blood of the lower vertebrates, as the amphibia. In *size*, they are about $\frac{1}{3200}$ inch in diameter and $\frac{1}{12000}$ inch in thickness. Various causes and conditions may, however, slightly increase or decrease their size.

Because of their extremely small size, the corpuscles are not really red when viewed singly with the microscope, but rather of a pale yellow or even greenish tinge. It is only when millions of them are *en masse* that the characteristic red color becomes apparent: scarlet red in arterial blood, purplish red in venous blood.

A peculiar inherent property of red corpuscles is to arrange themselves, when withdrawn from their retaining vessels, in the form of rolls of coin, adhering to one another by some peculiar affinity. To describe this condition the term *rouleaux* has been used. This peculiarity becomes particularly marked when there is an inflammatory state of the system. Formation of *rouleaux* can be prevented by the injection of physiological saline-solution.

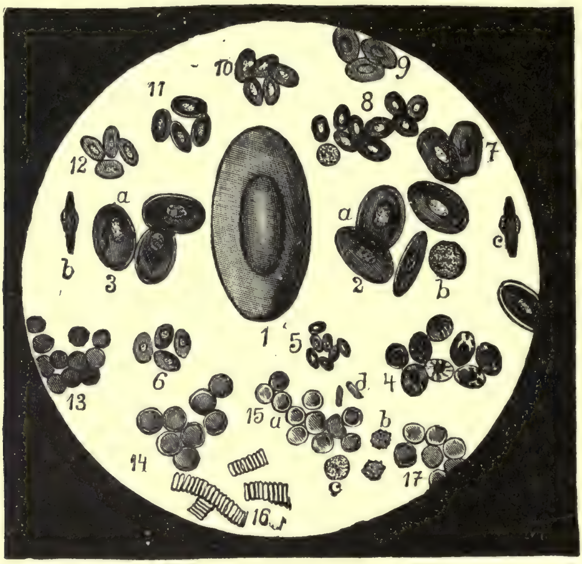


Fig. 47.—Blood-corpuscles of Different Animals. (THANHOFFER.)

1, *Proteus*. 2, *Rana esculenta:* a, upper view of same; b, white blood-corpuscles; c, side-view of red corpuscles. 3, Triton. 4, Snake. 5, Camel. 6, Turtle. 7, Salamander. 8, Carp. 9, *Cobitis fossilis*. 10, Cuckoo. 11, Chicken. 12, Canary bird. 13, Lion. 14, Elephant. 15, Man: a, upper view of same; b, crenated form; c, white blood-corpuscles. 16, Horse's cells in rouleaux. 17, Hippopotamus.

Parasites of Blood-corpuscles.—In the red corpuscles of some birds and fishes the microscopist frequently notices small, transparent spots. These are "pseudovacuoles," in which small parasites may be developed and later shed into the blood-stream. Within the

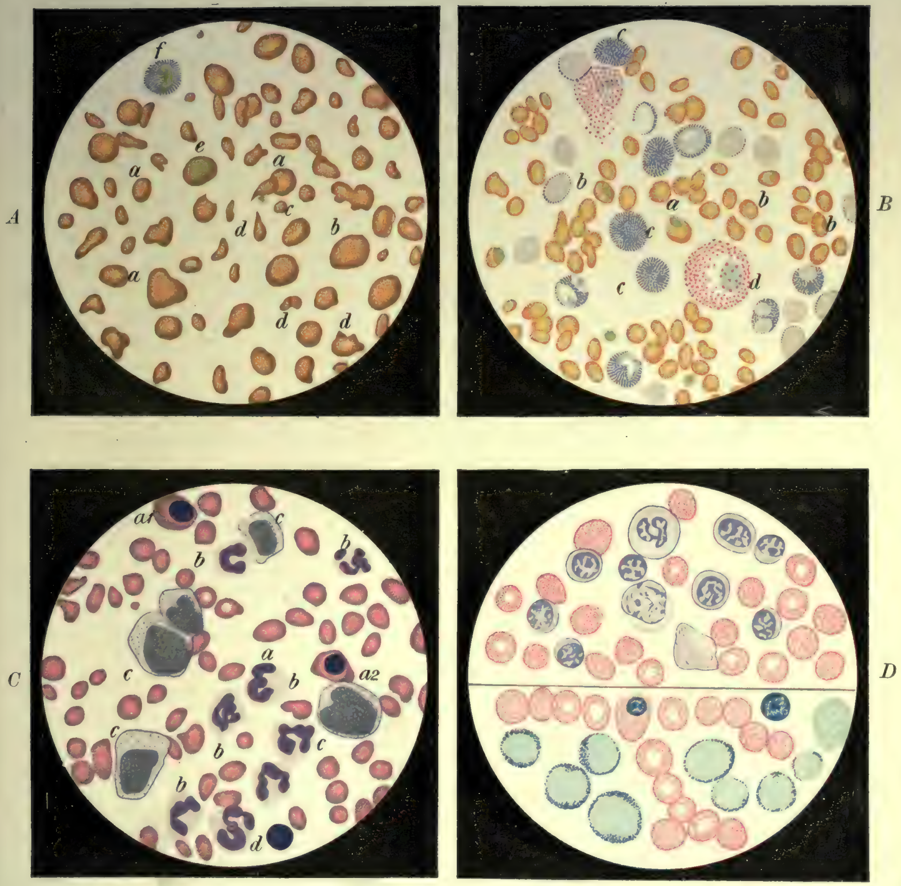


FIG. 48.

A.—PROGRESSIVE PERNICIOUS ANÆMIA. Ehrlich's triacid stain. Zeiss ocular 1, oil immersion $^1/_{12}$. *a*, normal erythrocytes; *b*, megalocytes; *c*, microcytes; *d*, marked poikilocytosis; *e*, megaloblast; *f*, polynuclear neutrophilic leucocyte. (Lenhartz-Brooks.)

B.—LIENAL (SPLENIC) LEUKÆMIA. *a*, normal erythrocyte; *b*, nucleated erythrocyte, nucleus eccentrically situated; *c*, polynuclear neutrophilic leucocytes; *d*, eosinophilic (myelo) cell. (Lenhartz-Brooks.)

C.—LIENAL (SPLENIC) LEUKÆMIA. *a1*, megaloblast; *a*, normal erythrocyte; *a2*, megaloblast, with anæmic degeneration; *b*, polynuclear leucocytes; *c*, "marrow cells" (myelocytes); *d*, large lymphocyte. (Lenhartz-Brooks.)

D.—ACUTE LEUKÆMIA. The upper portion is stained with Ehrlich's stain with eosin-hematoxylin; the lower portion is stained with the Plehn-Chenzinsky's stain. (Lenhartz-Brooks.)

red corpuscles of man, when affected by malaria, are developed the *Plasmodium malariæ.* Their passage into the patient's blood-plasma marks a paroxysm.

Number of Red Corpuscles.—The *number* of the corpuscles is usually spoken of in terms of cubic millimeters; thus, in man there are about 5,000,000 per cubic millimeter; in woman, about 4,500,000. These figures represent the average number per cubic millimeter, but even in health and in the same individual there may be wide variations from this standard, to say nothing of the extreme diminution experienced in certain pathological conditions.

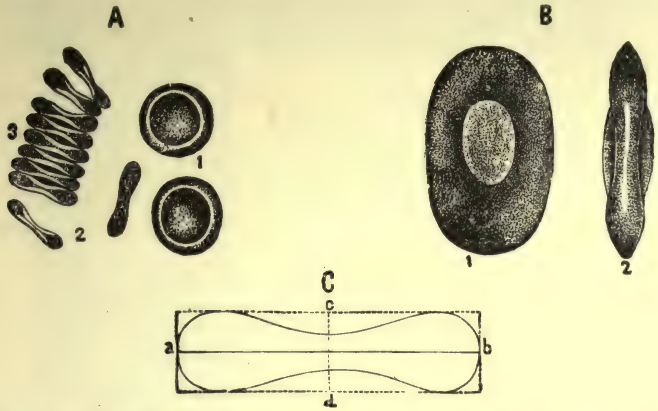


Fig. 49.—Human and Amphibian Blood-corpuscles. (Landois.)

A, Human red blood-corpuscles: 1, on the flat; 2, on the edge; 3, rouleaux of red corpuscles. *B*, Amphibian red corpuscle: 1, on the flat; 2, on edge. *C*, Ideal transverse section of a human red corpuscle, magnified 5000 times. *a-b*, linear diameter; *c-d*, thickness.

As the corpuscles are small bodies floating in a liquid medium, the student can easily understand why their number should be in inverse ratio to the quantity of plasma, when the unit, cubic millimeter, is considered. Copious sweating and the loss of much water by the bowels and kidneys occasion a temporary increase in their number. Normally, there is no difference as to the number of corpuscles in arteries and veins, provided there be no congestion in the latter.

A most interesting variation is that produced by habitation in high altitudes. A two weeks' sojourn in a high mountain has been known to show an increase from 5,000,000 to 7,000,000 per cubic millimeter. This is accounted for by a real increase in the manufacture of corpuscles.

Both the hæmoglobin-content and the corpuscles augment to the same degree in high altitudes. A return of the individual to a lower level is followed, in twelve to thirty-six hours, by a distinct fall both in hæmoglobin and the number of corpuscles.

In pernicious anæmia the marrow fat of the bones is invaded by the red marrow which normally exists at the extremities of bones, the whole marrow becomes red and a manufactory of red corpuscles. Iron and arsenic seem to stimulate the bone-marrow to produce red corpuscles. The final fate of red blood-corpuscles is to be broken up chiefly in the liver and excreted in the bile as bile pigment. If the disintegration of red corpuscles is very great the pigment may obstruct the bile capillaries and the bile be reabsorbed, producing "hæmatogenous jaundice."

There is both an increased destruction and an increased regeneration of red corpuscles in pernicious anæmia. The blood-count may be reduced to 143,000 per cubic millimeter.

In chlorosis the corpuscular-count falls considerably. A decrease to half a million per cubic millimeter is the lowest limit compatible with life.

Life-cycle of the Red Corpuscles.—The life of the red corpuscle is unknown. In experimental transfusion the red corpuscles disappear at the end of a variable period. The destruction of blood-corpuscles in extravasations does not give us any precise results. Observing the differences in color, consistency, and chemical reaction, it is found that they correspond to the different degrees of development. This shows that in the blood there is a constant destruction and renewal of the corpuscles.

Quincke believes that a red corpuscle lives from three weeks to a month.

Besides the liver, the spleen is also a place for the destruction of the red corpuscles.

Counting Red Corpuscles.—Various methods have been devised for counting the number of corpuscles, the instruments used receiving the name *hæmacytometers.* Modifications are numerous, but underlying all of them is one main principle, namely: the actual counting of the corpuscles within a certain measured bulk. To preserve the shape and integrity of these little bodies during the technique it is necessary to dilute the sample of blood with some solution whose specific gravity exactly equals that of the blood-serum. Some of this blood-solution is then placed upon a graduated slide beneath a microscope for counting, when the number per cubic millimeter is easily computed.

At this point the attention of the student will be directed to but two instruments: (1) the Thoma-Zeiss apparatus, and (2) the Daland hæmatocrit.

1. Thoma-Zeiss Apparatus.—The apparatus consists of two separate and distinct parts: a capillary tube and a counting chamber. The tube is for the purpose of measuring the amount of blood whose corpuscles are to be counted. By it also is accomplished the proper dilution in the upper, bulbed chamber. The capillary portion of the tube is graduated to 0.5 and 1.0 marks. Just above the capillary portion of the instrument is the bulbous portion containing a small glass ball to assist in the thorough mixing of blood and diluting normal saline fluid. Just above the bulb is the 101 mark. For drawing both blood and the diluting saline into the apparatus there is attached a piece of rubber tubing with a suitable mouth-

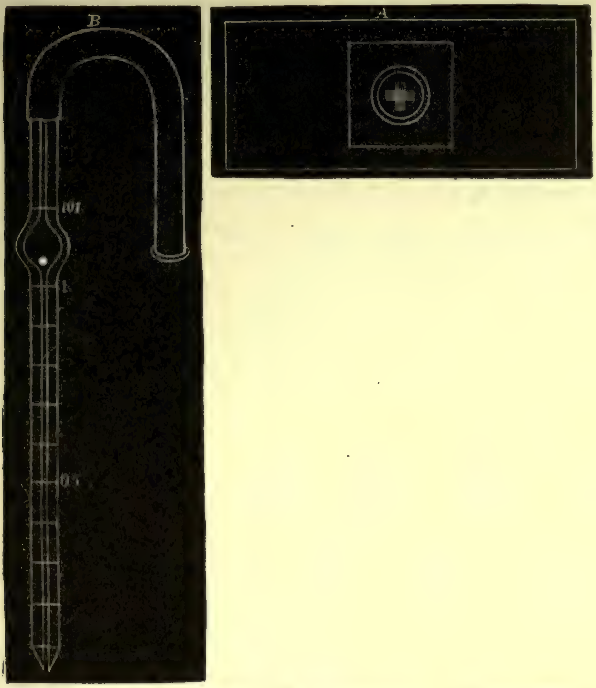


Fig. 50.—Hæmacytometer of Thoma-Zeiss. (Lahousse.)

A, Capillary glass tube. B, A glass slide upon which is a covered disc accurately ruled so as to present 1 square millimeter divided into 100 squares of $1/20$ millimeter each. 1, Blood is drawn up to this point. 101 represents normal saline-solution drawn up the tube, mixed with the blood drawn up to 1. In 101 parts the blood forms 1 part.

piece. With the blood up to the 1.0 mark and enough diluting saline to bring the whole quantity of liquid to 101, the dilution is 1 to 100.

The second portion of the instrument, known as the *counting chamber*, is constructed so as to enable one to count under the microscope all the cells in a known bulk of the diluted blood. In the center of a thick glass slide is cemented a cover-glass of accurately measured thickness with a hole in the center of about 1 centimeter in diameter. In the central area of this cover-glass there is also cemented to the glass slide a glass disc about 2 millimeters smaller in diameter and exactly $\frac{1}{10}$ millimeter thinner than the cover-glass. The glass shelf being exactly $\frac{1}{10}$ millimeter thinner than the cover-glass, it will readily be seen that if a second loose cover-glass be laid upon the first, the under surface of this loose cover-glass will be exactly $\frac{1}{10}$ millimeter above the upper surface of the glass disc. In this way there is secured a layer of fluid $\frac{1}{10}$ millimeter in depth. Furthermore, 1 square millimeter of the surface of the disc is outlined and subdivided by intersecting lines into 400 small squares. For convenience in counting, every fifth row of squares is divided into two by an additional line. The volume of diluted blood above each square of the micrometer will be $\frac{1}{4000}$ cubic millimeter. The average of 10 or more squares is then ascertained, which result is

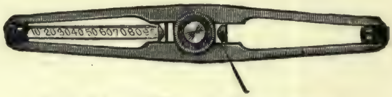


Fig. 51.—Daland's Hæmatocrit.

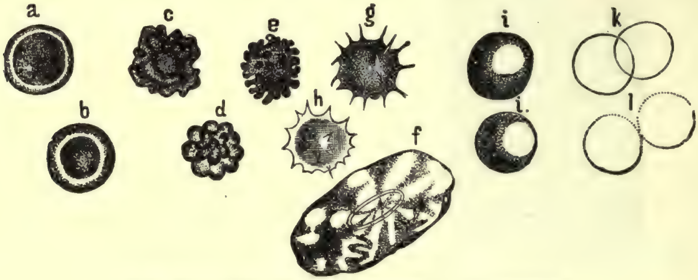


Fig. 52.—Red Blood-corpuscles. (Landois.)

a, *b*, Normal human red corpuscles with the central depression more or less in focus. *c*, *d*, *e*, Mulberry forms. *g*, *h*, Crenated corpuscles. *k*, Pale decolored corpuscles. *i*, Stroma. *f*, Frog's corpuscles acted upon by a strong saline solution.

multiplied by 4000 times 100 to give the number of corpuscles in a cubic millimeter of undiluted blood.

THE HÆMATOCRIT.—A rapid approximate determination of the relative percentage of the corpuscles may be made by *Daland's instrument.* The blood is sucked up the graduated tube *without dilution* and then centrifuged. The corpuscles rapidly accumulate at the end of the tube in an almost solid mass, and their collective volume can be directly read off. The estimate can be made with a small quantity of blood, and is, therefore, capable of being used for clinical purposes. Daland found that 50 was normal; this, multiplied by 100,000, gives the number of corpuscles in 1 cubic millimeter.

HÆMOLYSIS, OR LAKING OF BLOOD.

Experiments Upon the Blood.—Points of interest to the physiologist particularly and to the clinician incidentally have been disclosed as the results of some simple experimental work upon the blood-corpuscles. Each red corpuscle is seen to be composed of a fine meshwork, or stroma, consisting of noncolored, homogeneous protoplasm. Scattered throughout this framework is the iron-holding pigment, which gives color to the corpuscle and is the substance with which the oxygen-gas enters into loose combination. Any reagent which is able to sever the union between stroma and hæmoglobin causes the latter to pass into solution in the plasma. The once-red corpuscles then appear as transparent bodies. This makes the blood dark red, but *transparent,* since the coloring matter is in solution. When the blood is in this condition it is said to be "lake-colored."

This discharge of the hæmoglobin from the corpuscles is called hæmolysis. The substances which produce this state of affairs are hæmolytic agents.

Overton holds that the surface layer of the protoplasm of all animal and vegetable cells is impregnated with a layer of a compound of cholesterin and lecithin which permits of a slow or rapid exchange of substances between the cell and its medium. The static osmotic features of a cell independent of its inherent protoplasmic activity depends upon the solubility of substances in cholesterin-lecithin. Hence the cell-envelope is permeable to most organic poisons, alkaloids, phenol and antipyrin, whilst proteids or carbohydrates cannot possibly enter the cell in a similar manner. The hæmolytic action of saponine, solanine and digitaline is regulated by the nature of this envelope. Hedin has shown that the red corpuscles are very permeable to aldehydes, ketones and alcohols.

The action of certain *organic substances* is of considerable importance. Thus, bile and the alkaline salts of the biliary acids have the power to dissolve and destroy the red corpuscles with phenomena which resemble those produced by the action of chloroform. *Urea* in solution and excess of alkali also destroys them.

The lowering of osmotic pressure in the plasma by water will make the blood laky, an act of hæmolysis, because an excess of water lowers the osmotic pressure outside the corpuscle; then the water enters the corpuscles, discharges and dissolves the hæmoglobin.

The red corpuscles comport themselves in saline solutions as an element with a semi-permeable envelope containing a liquid.

For each sodium chloride solution there is such a degree of contraction that the red corpuscles remain the same as in the plasma. This is called an isotonic solution, and its osmotic pressure is the same as that of the plasma. If the water in the sodium chloride solution is proportionately increased, the blood-corpuscles absorb a part and swell. Here the osmotic pressure of the sodium chloride solution is lower than that of the plasma, and is called a hypotonic solution. When the osmotic pressure is higher than that of the plasma, then the red corpuscle gives out its water until the osmotic pressure of the cell contents is equal to the osmotic pressure of the solution. This is called a hypertonic solution.

The percentage of NaCl necessary to generate such a solution is, for frogs' blood, 0.65 per cent.; for blood of man, 0.95 per cent.

Hæmolysins.—Laky blood may also be produced upon the injection of the blood-serum of one animal into the blood of another kind of animal, the serum having the power to destroy the red corpuscles. The term "globulicidal action" covers this property of the serum.

But the term "globulicidal action" has been replaced by the term hæmolysis. This is not due to differences in osmotic pressure, but to a hæmolysin in the blood which is composed of two bodies, amboceptor and complement or alexin. The microbe of tetanus generates a tetanolysin. Snake venoms set free the hæmoglobin in red corpuscles. The action of foreign serum is not limited to an action only on the red corpuscles, for it may attack nerve and other cells. 0.04 cubic centimeter of serum of certain Italian eels by the vein kills the rabbit, with apparently an action on the vasomotor and respiratory centers. Dilutions of serum of certain Italian eels 1 to 15,000 or to 20,000 produces hæmolysis of the red corpuscles in other animals, and is, up to the present, the most powerful hæmolytic agent known.

As to *vitality,* it is known that the corpuscles of the blood that have escaped from the circulatory system, as well as those from defibrinated blood, when reintroduced into the living blood-stream, retain their vitality.

THE WHITE CORPUSCLES.

The white corpuscles are colorless, spherical little bodies which are a little larger than the red ones and much less numerous. Each is about $\frac{1}{2500}$ inch in diameter and is composed of granular protoplasm that is highly refractile and without any enveloping membrane.

In striking contrast to the erythrocytes, the leucocytes possess not only one, but usually three nuclei; even four are not uncommon. Within the nuclei may be defined several distinct *nucleoli.*

When examining a section of blood, it is at once a striking feature how few are the white as compared with the red corpuscles. In the average field but three or four are found, while at the same time hundreds of erythrocytes are noticed. The average is but *1* white for every *500* or *600* red ones.

This proportion does not pretend to convey an accurate idea of their relationship because of the frequent fluctuations of the white corpuscles even in a single day. They increase during digestion and diminish during abstinence. Seven thousand five hundred white corpuscles are found in a cubic millimeter of blood.

Bleeding, lactation, quinine, local suppuration, pregnancy, and leucocythæmia increase the white corpuscles; their number is diminished by large doses of mercury.

The proportionate number of leucocytes that is found in blood drawn from its containing vessels is no criterion of the number found within the blood-stream. As soon as blood is drawn from the body, for no accountable reason, an immense number of white corpuscles disappears. It is stated that there remain but one-tenth of the number previously found in circulation.

Colorless corpuscles are not essentially peculiar to the blood-stream nor to be found only in it, for similar corpuscles are found in lymph, chyle, adenoid tissue, the marrow of the long bones, and also as wandering cells in connective tissue, drawn thither by inflammation and by bacteria.

Varieties.—According to Ehrlich, they may be separated into *three groups,* the basis of classification depending upon the *staining proclivities* of the *granules* held within the cytoplasm. To the first group he gave the name *eosinophiles,* because the granules of this class of corpuscles stain best with *acid* aniline dyes. The *basophiles* comprise the second group and include those staining best with *basic* dyes. Last come the *neutrophiles;* their granules are capable of being colored only by the presence of neutral dyes. This classification is a very popular one, and holds a very prominent position in pathological circles.

White blood-corpuscles are classified in two varieties:—

I. Lymphocytes are without granules in the cell and without amœboid movement.

(*a*) Small mononuclear lymphocytes are about the size of a red blood-corpuscle, have a large, round, concentric nucleus, a small amount of cytoplasm, and are strongly basophilic, 20 per cent.

(*b*) Large mononuclear lymphocytes have a large, oval nucleus, located excentrically; cytoplasm relatively considerable, not granular, and are weakly basophilic, 1 per cent.

II. Leucocytes have a granular cytoplasm and amœboid movement.

(*a*) Transitional are mononuclear leucocytes, having a large nucleus, considerable granular cytoplasm, and neutrophilic granules. They are a transitional form between the large lymphocytes and the polymorphonuclear leucocytes, 7 per cent.

(*b*) Polymorphonuclear leucocytes have the amœboid movement well developed; the granules in the cytoplasm are neutrophilic; and the nucleus is divided into lobes, connected by bands, 70 per cent.

(*c*) Eosinophiles have a segmented nucleus, the granules in the cytoplasm are large and stain with eosin; they are oxyphilic, 2 per cent.

(*d*) Mast cells are small in number, with a polymorphic nucleus and basophilic granules, 0.½ per cent.

Amœboid Movement.—All the leucocytes have in common a very remarkable attribute of spontaneously changing their shape and thereby executing certain movements, which, from their great similarity to those performed by the micro-organism, amœba, have been termed *amœboid.* When the conditions of temperature and moisture are maintained at the proper standard, the leucocytes will be seen slowly to alter their shapes and to send out from their cytoplasm little processes into which the remainder of the leucocytes seem to flow, thereby causing a slight movement with change of position. This process repeated successively gives to the cell its power slowly to move from place to place, after having worked its way through the vessel-walls into the surrounding connective tissues. This locomotion is frequently termed the "wandering" of the cell.

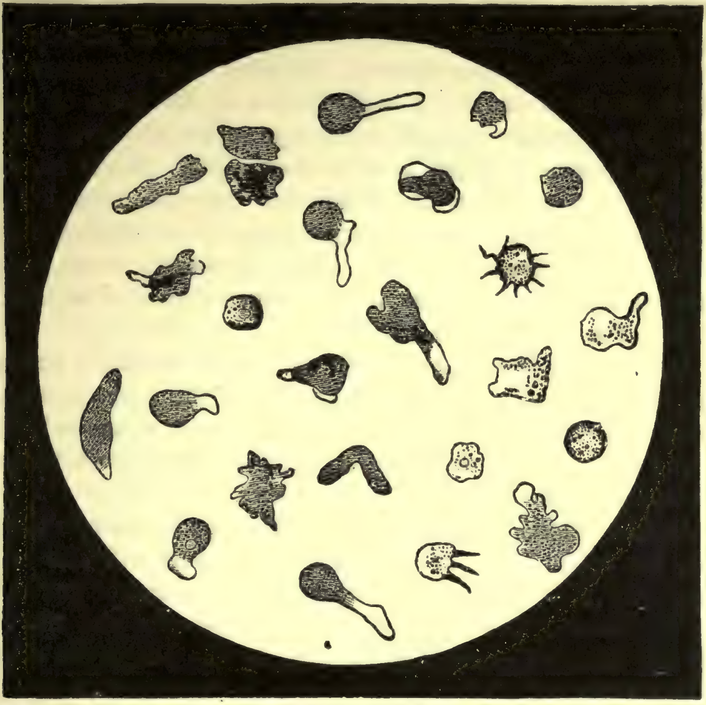


Fig. 53.—Leucocytes of Man, showing Amœboid Movement. (Landois.)

To their sticky exteriors there are frequently seen adhering fine pieces of broken-down cells, bacteria, and other foreign particles. By reason of certain internal circulatory movements in the protoplasm of the leucocytes, these adherent foreign particles may be drawn into the interior of the cell, where some are digested, and others excreted as effete matters.

Functions of the Leucocytes.—It is definitely known that the leucocytes play an important rôle in the process of blood-coagulation. Their relation to this most important process will be discussed under the head of "Coagulation." They are believed to help maintain the needed proportion of proteids in the blood.

Their most evident function is the protection of the economy from both harmless and pathogenic bacteria. This they accomplish by two methods. The first is by generating a defensive proteid which, when imbibed by the bacteria, kills them. The second and more usual method is that of drawing into their interiors the various bacteria, together with the *débris* resulting from lesions, and digesting them. From this apparent consumption of foreign particles they have gained for themselves the name of *phagocytes*, and the act is known as *phagocytosis*. The seat of the presence of the bacteria marks a miniature battlefield, with the hosts of bacteria drawn up on one side in battle array against the leucocytes, the two armies to become engaged in a death-struggle. If the leucocytes, now termed phagocytes, are victorious, they not only kill their adversaries, but even remove every vestige of the combat, aided by the fixed connective-tissue cells. Those leucocytes which come out of the affray unharmed and are no longer needed, find their way back into the blood-stream.

If, however, the bacteria, with their toxic secretions and excretions, are too powerful for the phagocytes, the latter succumb, to become pus-corpuscles. When the pus has been removed by drainage and the action of other leucocytes, the broken-down tissues are replaced by regenerating connective tissues.

Bacteria alone are not the provocation for attack by the phagocytes, for the presence of other foreign matters will also call out an assault. It is well known that surgical ligatures of gut and silk that are allowed to remain *within* the body-cavity and tissues are gradually removed, particle by particle, by the phagocytic action of the leucocytes.

The absorption of the tails of tadpoles and other batrachians is due to phagocytic action.

Diapedesis.—By reason of their locomotive tendencies the leucocytes and red corpuscles are able to make their way through the walls of the capillaries; this emigration has been styled *diapedesis*. There are several stages before the leucocyte finally makes its exit, namely: slowing of the current with the adherence of the cell to the side of the blood-vessel, and projection of processes, to be followed by the gradual exit of the entire leucocyte. This process occurs to some extent in health, but is greatly exaggerated by inflammation, presence of bacteria, etc. Circumscribed collections outside of the vessels often form abscesses, the leucocytes then receive the name *pus-corpuscles.* The leucocytes in this condition usually are dead and show signs of fatty degeneration. Frequently red corpuscles follow in the wake of the white ones, passing through the openings in the vessel-walls made by the former.

In acute fevers and septic processes, as the temperature rises there follows a decrease in the number of erythrocytes, with a corresponding increase of leucocytes.

Origin of Leucocytes.—The source of the colorless corpuscles seems to be rather extended. They originate in the bone-marrow and spleen, but the credit for greatest production belongs to the lymphoid tissues and lymphatic glands. From these latter sources the leucocytes enter the lymph-circulation, from thence to be emptied into the blood-stream. After having once gained entrance to the blood-circulation there is rapid multiplication to keep up the proper supply, since many succumb to the poisons secreted and excreted by the various bacteria.

One set of observers assert that all white corpuscles are derived from a single type of cell; that the nongranular can form the granular. Another set of observers hold that there is no relation between the granular and nongranular, and that one is never transformed into the other.

In lymphatic leukæmia the red marrow is transformed into a mass of adenoid tissue, with the natural consequence that the granular cells disappear almost entirely. The large clear cells with a single nucleus in the marrow are the mother-cells of the granular leucocytes, which, by the protoplasmic deposit of granules, become granular myelocytes, in which the nuclei are still single, and are largely present in myelogenous leukæmia.

The marrow produces the granular cell, whilst the lymphatic tissue generates the nongranular cell. Muir has calculated that all the white cells in the blood would not suffice to form more than an ounce of pus. The average life of the leucocyte is a few days. The spleen is largely a place of destruction of leucocytes.

Blood-plates, Hæmatoblasts of Hayem and Hæmaconien or Blood-Dust.—In addition to the erythrocytes and leucocytes found floating in the *liquor sanguinis,* there have been discovered other numerous, smaller bodies, termed blood-plates and elementary granules.

The *blood-plates* are pale yellow or colorless discs; round, oval, or crescentic in shape; and varying within wide ranges as to size, being about half the size of the red corpuscle. Deetjen states that blood-plates are nucleated and contain protoplasm with an amœboid movement. In blood that has been drawn from the vessels they diminish very rapidly both in numbers and size, becoming gradually dissolved in the plasma. They are readily seen in blood treated with 1 per cent. of solution of osmic acid.

As to their nature, there is some diversity of opinion, but the consensus of thought seems to be in favor of the plates being formed bodies, and not precipitates. They have been found to contain the same elements chemically as the nuclei of the leucocytes.

The number of blood-plates is about half a million per cubic millimeter. In the defibrination of blood by whipping two periods can be distinguished: in the first, a thick layer of platelets collect on the bunch of wires, whilst in the second these bodies coalesce into a granular mass in which layers of fibrin collect. The platelets have numerous processes. Blood-plates can be seen in the circulating blood of the bat, mouse and guinea-pig.

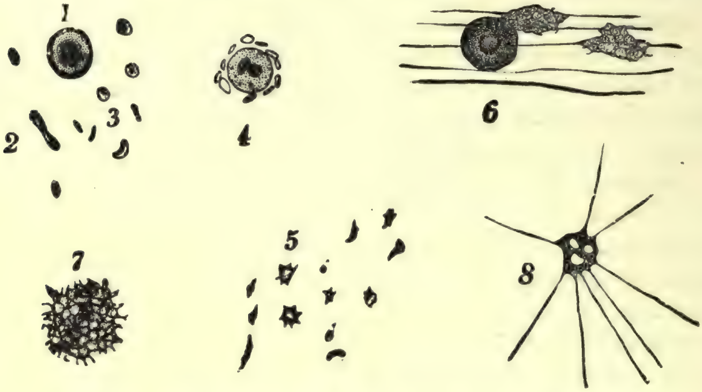


Fig. 54.—Blood-plates and their Derivatives. (Landois.)

1, Red corpuscle on the flat. 2, On the side. 3, Unchanged blood-plates. 4, Lymph-corpuscle surrounded by blood-plates. 5, Altered blood-plates. 6, Lymph-corpuscle with two heaps of blood-plates and threads of fibrin. 7, Group of fused blood-plates. 8, Small group of partially dissolved blood-plates with fibrils of fibrin.

Endocarditis and injury to the wall of a vein, damaging the blood, gives rise to the formation of a white thrombus, which is formed by an adhesion of red corpuscles to the parts. This thrombus extrudes the platelets, which consist of nucleo-proteid, and form more thrombi. The function of blood-plates is to assist in coagulation and in the formation of thrombi. Blood-plates are less in purpura. The lessened coagulability here may in part be caused by a diminution of the fibrin, which is supposed to depend upon the plates for its source. Blood-plates are increased in leukæmia.

Hæmaconien are smaller than the blood-plates, and appear to be composed of portions of the *protoplasm* of leucocytes. They contain proteid and fatty matters.

FORMATION OF RED BLOOD-CORPUSCLES.

The red corpuscles, like every other portion of the economy, perform their allotted task and round of existence, to finally die and disappear.

The origin of the red corpuscle as to *time* may be spoken of as that which occurs during *intra-uterine life* and that occurring during *extra-uterine life*.

During Intra-uterine Life.—The corpuscles which first appear in the human embryo owe their existence to a very simple origin. They differ in some respects from those that appear later during intra-uterine life, and very materially from those formed during life outside of the uterus.

The wall of the yelk-sac, situated entirely outside of the body of the embryo, is the seat of the first vessels and blood. In the chick the corpuscles appear during the first days of incubation and before the appearance of a heart. At the end of the first day, surrounding the early embryo there appears a circular, vascular area made up of cords of cells in which are developed the first evidences of the vessels and corpuscles. The corpuscles appear in groups within this branched network of mesoblastic cells, where they form the "blood-islands" of Pander. Presently the cords of mesoblastic cells which compose this network begin to become vacuolated and hollowed out to constitute a system of branching canals, at the same time that their cells acquire the endothelial type. The small, nucleated masses of protoplasm, known as the "blood-islands," undergo disintegration, whereby their nuclei are set free soon to collect around themselves a thin envelope of protoplasm. These constitute the primitive red corpuscles, and are the only bodies contained within the blood during the first month. In the meantime they have been acquiring a reddish hue, which marks the advent of the hæmoglobin. As the canals become extended and branched eventually to connect with the heart as its system of vessels, there appears within them a fluid into which are emptied the red corpuscles. Thus is completed the circulation. According to Klein, the nuclei of the protoplasmic vessel-walls multiply to form new cells. The primitive corpuscles are spherical in shape, nucleated, and possess amœboid movements. They undergo multiplication by karyokinesis.

During the fœtal period the protoplasm of the *connective-tissue corpuscles,* derived from the mesoblast, contains cells of the size and appearance of blood-corpuscles. The mother-cells elongate, throw out processes which become hollowed out and branched until they reach the regular circulatory vessels, with which they unite to empty into them their fluid and cells. During this period also they seem to be developed from the liver, spleen, and red bone-marrow.

During Extra-uterine Life.—For some time after the birth of the mammal, nonnucleated corpuscles are still formed in the spleen, liver, and connective-tissue cells, but by far the most important and prolific seat is in the *red marrow of bones.* It is in the bones of the skull, trunk, and ends of the long bones that blood-formation is most extensive, since the shafts of these bones contain a yellow, fatty substance which is nonproductive. Within the marrow are seen numbers of nucleated, red cells, which are very similar to the corpuscles of the embryo, and which, like them, multiply by karyokinesis. From these repeated divisions there result nonnucleated red corpuscles which are washed into the circulation. The blood-forming cells have received the name of *erythroblasts,* and they are particularly numerous after copious hæmorrhage, when the lost blood is being replaced by more active formation. At such times some erythroblasts may appear in the blood-stream, having been forced out prematurely, so active is the function of the red marrow in striving to repair the damage done. These soon lose their nuclei while in the blood-stream. If the loss by hæmorrhage has been particularly severe, the yellow bone-marrow and spleen assist in blood-manufacture, for in the latter and in the splenic vein are found nucleated, red corpuscles identical with those of the red marrow of bone.

DESTRUCTION OF THE RED CORPUSCLES.

The student can gain some comprehension of the number of corpuscles which must constantly be undergoing disintegration when he recalls the fact that all of the pigmentary matters in the body owe their existence, directly or indirectly, to the hæmoglobin of these little bodies. The quantities of urinary and biliary pigments alone that are excreted from the economy are considerable.

Physiologists have proved that there are fewer red corpuscles in the hepatic than in the portal vein. The bile-pigments are formed by the liver-cells; these coloring matters contain only traces of iron, while the hepatic cells are rich with it. They give the characteristic test for iron when treated with hydrochloric acid and potassium ferrocyanide.

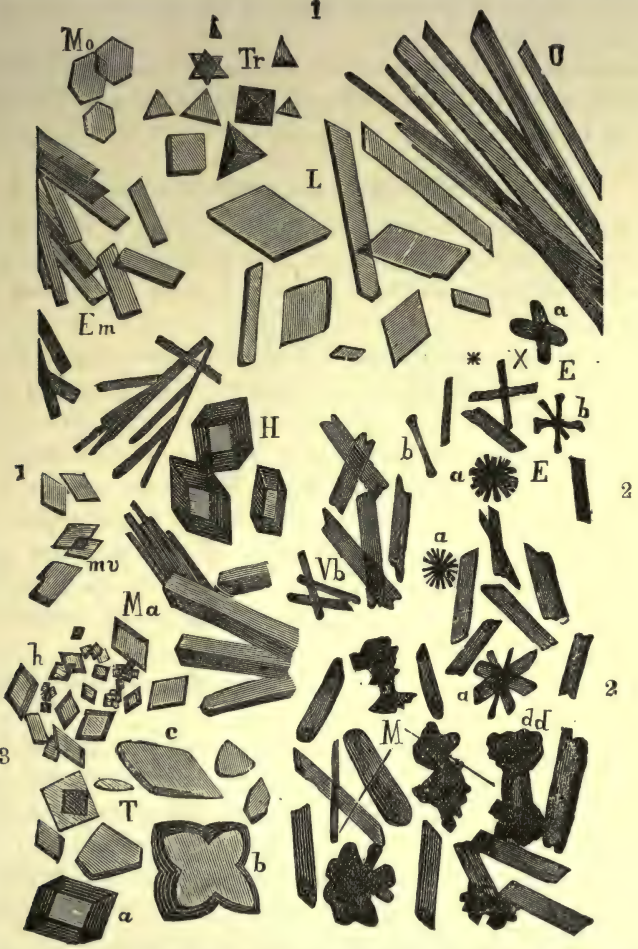


Fig. 55.—Blood-crystals of Man and Different Animals. (Thanhoffer and Frey.)

1, Hæmoglobin crystals: *Mo*, squirrel; *Tr*, guinea-pig; *M*, groundmole; *L*, Horse; *Em*, man; *H*, Marmot; *Ma*, cat; *T*, cow; *mv*, from venous blood of a cat. **2**, Hæmatin crystals; *E*, man; *Vb*, sparrow; *M*, cat. **3**, Hæmatoïdin crystals from an old extravasation of the blood in man.

Only traces of the iron are excreted as a constituent of the bile.

The presence of iron in the spleen has long made this organ seem a cradle to many physiologists where erythrocytes are born and nourished. But the presence of this same element advances an argument equally as strong in favor of the spleen being the grave for these same bodies.

Pathologically, masses of iron substances are found within the spleen, liver, and red bone-marrow when abnormal disintegration occurs, as in *anœmia.*

COMPOSITION OF CORPUSCLES.

A very notable fact about the red corpuscles is the low content of water. Muscle and nerve tissue have about 75 per cent. of water. The feeble metabolic changes in the corpuscle are shown by this want of water.

The red corpuscles consist of a stroma containing in its meshes a peculiar proteid hæmoglobin. Chemically they are made of 60 per cent. of water and 36 per cent. of hæmoglobin, the remaining 4 per cent. representing the stroma, which is made up of lecithin, cholesterin, and nucleo-proteid. The white corpuscles consist of solids and water. The solids are gluco-proteids and nucleo-proteids and a small amount of albumin and globulin. The protoplasm may also contain glycogen and fat. The nucleus is made up of nucleo-proteids, nuclein, and nucleic acid. The phosphorus content of the nucleus is greater than that of the protoplasm.

The table on the next page is the result of the analyses reported by Halliburton.

The other named constituents are common to the two kinds of corpuscles. The mineral components are principally the chlorides of potassium and sodium and the phosphates of calcium and magnesium, the phosphates being in greater proportion. It will be remembered that the sodium salts assume greater proportions in the plasma. The nucleo-proteid obtained from the white corpuscles is the precursor of the fibrin-ferment of coagulation.

Hæmoglobin.—This is the pigment matter of the red corpuscles. Hæmoglobin is a proteid composed of globin, a histon, and hæmatin. Its principal characteristics are: (1) its ability to combine chemically with oxygen and other gases, (2) its spectroscopic phenomena, (3) its crystallization, and (4) the fact of its containing iron.

It is by virtue of the presence of this hæmoglobin that the red corpuscles are capable of performing the function of oxygen-carrying—carrying it from the *external* respiration in the lungs to the

CHEMICAL COMPOSITION OF BLOOD.

PLASMA.

Average, 52% **Maximum, 56.7%** **Minimum, 45.6%** **Take 100 parts**	Water				90.29%
	Solids (9.71%)	Organic (8.86%)	Proteids	Serum-albumin Serum-globulin	7.9 %
				Fibrin	0.4 %
			Extractives:	Fats, etc.	0.56%
		Inorganic (0.85%)	Soluble salts	$NaCl$ KCl $NaHCO_3$ Na_2HPO_4	0.85%
			Insoluble salts	$CaHPO_4$ $CaSO_4$	
					100.00%

CORPUSCLES.

Average, 48% **Maximum, 54.4%** **Minimum, 43.3%** **Take 100 parts**	Water					68.80%
	Solids (31.2%)	Organic (30.4%)	Proteids (29.79%)	Hæmoglobin (27%)	Hæmatin (Fe) Globulin	27.36%
				Globulin		2.43%
			Fats	Lecithin Cholesterin		0.61%
		Inorganic (0.8%)	KCl $NaCl$ $MaCl_2$ $CaHPO_4$ $Mg_3(PO_4)_2$			0.80%
			Fe (see Hæmatin).			
						100.00%

internal respiration in the cells of the tissues. The hæmoglobin molecule possesses the property of linking to itself an oxygen molecule, forming a compound known as *oxyhæmoglobin.* The union of the two molecules is so unstable that the presence of an easily oxidized body, or of an atmosphere with a lower oxygen pressure, separates the two, the oxidizable body and the atmosphere taking up the oxygen. Oxyhæmoglobin, minus oxygen, is usually termed *reduced hæmoglobin;* better, however, simply hæmoglobin. Oxyhæmoglobin is most abundant in arterial blood; that is, blood that has received its oxygen from the lungs during respiration and is then on its way to supply the needs of the cells of the tissues. Oxyhæmoglobin behaves as an acid. Ordinary venous blood, upon exposure to the air for a considerable length of time, becomes bright red because of the union of the oxygen of the air with the hæmoglobin of the blood.

Crystallization of Hæmoglobin.—The hæmoglobin is contained within the stroma of the corpuscles. In form, the crystals of the blood of man and of the great majority of animals are that of rhombic prisms or needles which belong to the rhombic system; in the squirrel they are six-sided plates.

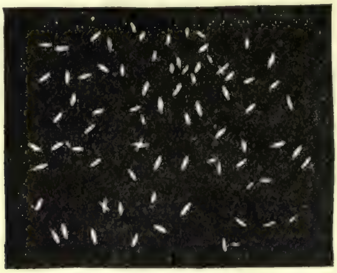


Fig. 56.—Teichmann's Hæmin-crystals. (Lahousse.)

Hæmoglobin crystals are readily broken up by the addition of an acid or an alkali into two parts: *hæmatin* and *globin*. *Hæmatin* is a brown pigment, representing the cleavage product of hæmoglobin in the presence of oxygen. It contains all of the iron of the decomposed crytals, and is not crystallizable. In addition to the iron, it contains the four chief elements of proteid bodies: carbon, hydrogen, oxygen, and nitrogen. *Globin* is the proteid element of the hæmoglobin. It contains all the sulphur, and constitutes the major proportion of the hæmoglobin molecule, which is 16,000 times heavier than a molecule of hydrogen.

The stroma of the red corpuscles is as 1 to 12 to the quantity of hæmoglobin. The whole quantity of blood of a man of medium weight holds about 680 grams of hæmoglobin. E. T. Reichert prepares blood-crystals by laking defibrinated blood, of a dog or guinea-pig, with acetic or ethylic ether, and then adding a solution of 1 to

5 per cent. of ammonium oxalate. Under the microscope this mixture will soon show the formation of crystals.

The hæmoglobins of different animals are not identical for the following reasons: They do not crystallize with the same ease, the crystals are not of the same shape, they do not contain the same proportion of water of crystallization, their solubilities are not the same, and the proportion of iron differs. Dr. E. T. Reichert has confirmed these facts by a study of the general form of the crystals and a measurement of their angles.

Hæmin.—Hæmin is the decomposition-product that results from the action of hydrochloric acid upon hæmatin. The hæmin crystals are small rhombic plates and prisms. The finding of the crystals of Teichmann constitutes the best-known clinical test for the detection of blood. The crystals are prepared by adding a small crystal of common salt to dry blood on a glass slide, and then an excess of glacial acetic acid. The preparation is then gently heated until bubbles of gas are given off. Upon cooling, the characteristic hæmin crystals are formed. By transmitted light the crystals appear as mahogany-brown, but by reflected light they are bluish black.

Chemical Properties.—Hæmin crystals are insoluble in water, alcohol, ether, and chloroform. Very strong sulphuric acid is capable of dissolving them. Should this solution be evaporated to dryness and the residue properly treated, there will be produced a brown, amorphous powder. This product is known as *hæmatoporphyrin.*

Hæmatoporphyrin is iron-free hæmatin. It is frequently found in pathological urines, while traces of it are to be found in normal urine.

It has the same formula as bilirubin, isomeric, but not identical. Mesoporphyrin, containing one atom of oxygen less than hæmatoporphyrin, is said to be identical with hæmatoidin.

Chlorophyll, the pigment of plants concerned in respiration and containing iron, gives a body, phylloporphyrin, on cleavage by acids. It is similar to hæmatoporphyrin.

The two important pigments, animal and vegetable, hæmoglobin and chlorophyll are both related to hæmopyrrol, derived from pyrrol, which shows a very interesting chemical relation between the coloring matters of the animal and vegetable kingdom.

Hæmatoidin.—In old blood-extravasates in the brain, hæmatoidin is found in crystals. It is an iron-free derivative of hæmoglobin, identical with bilirubin.

Methæmoglobin.—Methæmoglobin is prepared chemically by adding amyl nitrite to blood. It contains the same amount of oxygen as hæmoglobin, but, owing to its different combination, the oxygen cannot be removed even in a vacuum; hence it cannot be a transporter of oxygen to the tissues. Potassium chlorate and the continued use of antipyrin and acetanilid will produce methæmoglobin.

Carbon-monoxide Hæmoglobin, or Carboxyhæmoglobin.—With carbon-monoxide gas (CO) hæmoglobin forms a compound similar to oxyhæmoglobin, but known as *carbon-monoxide hæmoglobin.* This union is much more stable than the preceding, so that when carbon-monoxide gas is breathed in excess death results from asphyxia, since the tissues are prevented from receiving their proper supply of oxygen.

Carbon-monoxide results from the incomplete combustion of carbon in coal and charcoal stoves. Its poisonous properties are caused by its combining so firmly with the hæmoglobin of the corpuscles that it prevents union with oxygen, and so produces asphyxia. The blood of both veins and arteries is bright, cherry-red in color. In poisoning from this gas, artificial respiration with saline transfusion is sometimes of avail.

For a better understanding of the import of the absorption bands of the coloring matters in the blood, a brief description will be given of the instrument whereby they are studied.

THE SPECTROSCOPE.

When *white* light, or that which reaches us from the sun, passes from one medium into another more dense, it is decomposed into several kinds of light, a phenomenon to which the name *dispersion* is given. Thus, when a pencil of the sun's rays is passed through a prism of flint glass, it is broken up into the seven colors of the spectrum. This band of colors may be seen naturally in the form mentioned as being placed inside the apparatus and is reflected up through the slit belonging to the compound prism. If any incandescent object is placed in a suitable position with reference to the aperture its spectrum will be obtained and will be seen on looking through it. *F* shows the position of the field-lens of the eyepiece. *G* is a tube made to fit the microscope to which the instrument is applied. To use this instrument insert *G* like an eyepiece in the microscope tube, taking care that the slit at the top of the eyepiece is in the same direction as the slit below the prism. Screw on to the microscope the object-glass required and place the object whose spectrum is to be viewed on the stage. Illuminate with stage mirror if transparent. Remove *A* and open the slit by means of the milled head *H* at right angles to *D*, *D*. When the slit is sufficiently open the rest of the apparatus acts like an ordinary eyepiece, and any object can be focused in the usual way. Having focused the object, replace *A* and gradually close the slit till a good spectrum is obtained. The spectrum will be much improved by throwing the object a little out of focus. Every part of the spectrum differs a little from adjacent parts in refrangibility, and delicate bands or lines can only be brought out by accurately focusing their own parts of the spectrum. This can be done by the milled head *B*. When spectra of very small objects are viewed, powers of $\frac{1}{2}$ inch to $\frac{1}{20}$ may be employed.

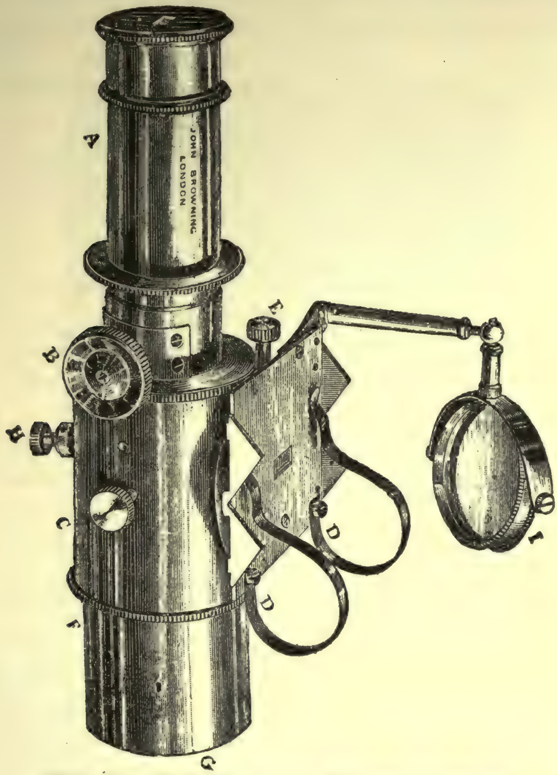


Fig. 57.—Sorby-Browning Microspectroscope.

These bands represent the light absorbed by the colored medium.

For the same substance the bands are always identical and similarly placed. Thus, a solution of oxyhæmoglobin of a certain strength gives *two bands,* reduced hæmoglobin gives only *one.* The other derivatives, methæmoglobin, hæmatin, hæmin, etc., though similar to hæmoglobin when viewed with the naked eye, yet each gives characteristic absorption bands in various positions.

Hæmochromogen is produced by treating an alkaline hæmatin solution with ammonium sulphide. It is reduced alkaline hæmatin.

Carbon-monoxide hæmoglobin, oxyhæmoglobin, hæmochromogen, and hæmatoporphyrin have two characteristic bands in their spectra.

By adding ammonium sulphide you can distinguish between oxyhæmoglobin and carbon-monoxide hæmoglobin, since the two bands of oxyhæmoglobin disappear, whilst those of carboxyhæmoglobin remain unaltered.

Hæmochromogen bands are to the violet side and hæmatoporphyrin to the red side of the bands of oxyhæmoglobin in the spectrum. Acid hæmatin, alkaline hæmatin, reduced hæmoglobin, and methæmoglobin can each produce a band on the red side of *D* line. A reducing agent makes this band vanish in the case of methæmoglobin or alkaline hæmatin, and produces reduced hæmoglobin or reduced hæmatin. Reduced hæmoglobin can be temporarily reoxidized by shaking the solution.

Picro-carmine gives a two-banded spectrum, but it differs in position from the double bands of oxyhæmoglobin. They are unaltered by ammonium sulphide, whilst oxyhæmoglobin gives the double band of reduced hæmatin by the addition of ammonium sulphide.

The *amount* of hæmoglobin as calculated by various methods and instruments has been found to be in man, 13.77 per cent.; in woman, 12.59 per cent. Pregnancy reduces the quantity from 9 to 12 per cent. Normally there are two periods in a person's life when the amount of hæmoglobin attains maximum limits—in the blood of the newborn and again between the years twenty-one and forty-five. Pathologically there follows a decrease during recovery from febrile conditions during phthisis, cancer, cardiac disease, chlorosis, anæmia, etc.

It is known that dry hæmoglobin contains 0.4 per cent. of iron, and that all the iron of the blood is held by the hæmoglobin of the red corpuscles. The amount of iron in the blood is about 45 grains.

Colorimetric methods consist in making comparisons between a standard solution of a known strength and the test solution of blood to be examined, water being added to the latter until the exact shade of the standard solution is obtained.

Von Fleischl's Hæmometer.—This instrument consists of *A*, a cylindrical cell for holding the prepared blood; *D*, a graduated wedge-shaped piece of colored glass with which to compare the solution of blood; *H*, a stand with a rack and pinion; and a capillary tube for measuring the quantity of blood required.

1. The cell (*A*) is a cylindrical metallic chamber divided by a fixed partition into two equal compartments, open at the top, but closed at the bottom by a base of glass. One of these compartments is to be filled with distilled water, the other with the proper quantity of blood dissolved in distilled water.

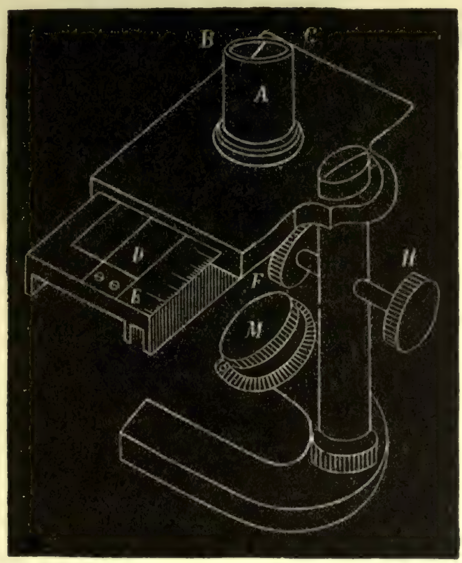


Fig. 58.—Von Fleischl Hæmometer. (Lahousse.)

A, Mixing vessel with two compartments: B, for diluted blood; C, for pure water, reposes over the colored prism of glass, D. E, Scale to read off amount of hæmoglobin. M, A mirror to reflect light. H, Milled wheel that moves D.

2. The colored glass wedge (*D*) is fitted to a metal frame, so that it can be adjusted in the stand and moved from side to side by the rack and pinion. When in position the glass wedge moves directly beneath that part of the cell which contains the distilled water, thus enabling one to compare the color of the glass with that of the dissolved blood which fills the adjoining compartment of the

cell. The wedge is graduated at *E* from 1 to 100, the figures representing the percentage of hæmoglobin in the specimen of blood as compared to normal blood containing 13.7 per cent. of hæmoglobin.

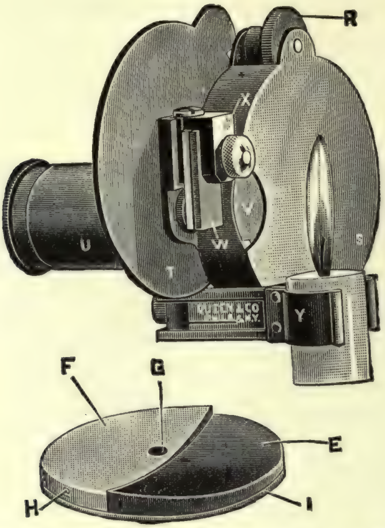


Fig. 59.—Dare's Hemoglobinometer. (Lenhartz.)

The upper figure represents the instrument ready for use (one-half actual size). *R*, Milled wheel by which the color-prism is rotated. *S*, Case inclosing color-prism, showing stage upon which the blood-pipette slides. *T*, Movable wing pivoted to case. (When drawn outward screens the eyes of observer from the light. When not in use lies superimposed upon the circular prism case.) *U*, Telescoping camera-tube in position for examination. *V*, Opening in prism case, admitting light for illumination of color-prism. (The white glass disk of prism is seen inside.) *W*, White glass of blood-pipette. *X*, Pipette clamp held in position on the stage by grooves and guides. *Y*, Detachable candleholder. *Z*, Rectangular opening in edge of case for reading hæmoglobin percentage indicated by beveled blade.

The lower figure is the color-prism. *E*, Prism of colored glass. *F*, Semicircle of white glass, the edge carrying the index hæmoglobin percentage etched and filled. in with black. *G*, Hole in which hub is fixed with rubber washers. (Pivots in center of case hold the prism firmly in place.) *H*, Index of hæmoglobin percentage etched in black. *I*, Disk of white glass which serves the same purpose as in the blood-pipette, breaks the glare of direct light, and furnishes a white background to view the shades of color.

3. Besides the support for the glass wedge and frame, there is a white plaster mirror (*M*) which furnishes the diffused light required in the test.

4. The capillary tubes are carefully prepared to hold the proper quantity of blood. The size of these tubes varies, and on the handle of each is stamped a number indicating its capacity.

DARE'S HÆMOGLOBINOMETER.

Dare's instrument is on the same principle as Von Fleischl's, except it compares a film of undiluted blood with a wedge of colored glass.

The essential parts of the instrument are an automatic pipette for collecting the blood and a graduated color comparison to measure the percentage of hæmoglobin contained therein. In making an observation, the instrument is held very much as a field glass, that is, up before the eyes, which are screened from the candle light by it. If the reading is 100, the hæmoglobin is normal; if the reading is 70, there is 70 per cent. of the normal.

To use the instrument, a puncture is made in the lobe of the ear; the first drop of blood is wiped away, whilst the second, which should correspond in size to a drop of water, is touched as it emerges from the wound to either of the three free edges of the pipette, held horizontally, which fills automatically to its margin by capillary attraction. When filled, the excess upon the edge presented to the blood drop is removed by quickly wiping it as the pipette is withdrawn.

PHYSICAL PROPERTIES OF THE PLASMA.

Plasma is the fluid part of the blood as it occurs in a healthy condition within the circulatory system. However, upon its removal from the body there is formed in it a solid substance, called fibrin, from elements which it previously held in solution. The fluid which surrounds the clot is termed *serum*; it is plasma minus fibrin. Plasma is described as a clear, somewhat viscid fluid; that of man, when strata are examined, is colorless; when in bulk it is slightly yellow because of the presence of a pigment.

CHEMICAL PROPERTIES OF PLASMA AND SERUM.

In order to examine plasma, a very great amount of caution is necessary to prevent its coagulation, even after separating the corpuscles. The most common methods for obtaining it in a liquid state are by the use of the "living test-tube"—an excised piece of jugular of a horse filled with blood, and cold as an environment. It has been found that serum differs from plasma only in respect to certain porteids, and, as it is so much easier to handle the serum, the latter is principally used for experimentation.

Chemically the plasma is composed of *inorganic* and *organic substances,* with *certain gases.*

Inorganic Constituents.—The plasma's greatest factor is water. It is this which gives it fluidity and is present to the extent of 90 per cent. There are present many salts; sodium chloride, carbonate of soda, chloride of potassium, sulphate of potassium, phosphate of calcium, phosphate of sodium, and phosphate of magnesium. The first two occur in the greatest amounts, the remaining ones only as traces. It is carbonate of soda that gives to plasma its ability to absorb carbonic acid and it also contributes much to its alkalinity.

Organic Constituents.—These components are readily divisible into *proteid* and *nonproteid* groups.

The Proteids are:—

1. One albumin (serum-albumin).
2. Two globulins, termed serum-globulin and fibrinogen.
3. A nucleo-proteid.

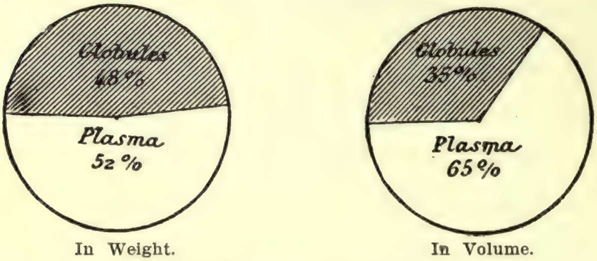


Fig. 60.—Relative Proportion of Corpuscles and of Plasma. (Human Blood.) (Langlois.)

The classes of proteids present *various solubilities in neutral salt solutions,* by appreciation of which they are able to be separated from one another.

The *albumins* upon half-saturation with ammonium sulphate remain in solution, while the globulins and nucleo-proteids are precipitated. The precipitate is removed by filtrations, or the albumins may themselves be precipitated by saturation with ammonium sulphate.

The *globulins* almost universally possess the characteristic of coagulating when heat of 75° C. is applied to them. In man the globulins make up about 3 per cent. of the total serum.

Fibrinogen is also a globulin. It is precipitated by half-saturation with NaCl thus making its differentiation from serum-globulin a comparatively easy task. Upon precipitating with NaCl, if a lime salt be added, the precipitate partakes of the nature of a fibrin-clot or coagulum, but it is not true fibrin, since it is a combination of fibrinogen with lime.

Nucleo-proteid of Plasma.—About the only characteristic that is known in connection with the nucleo-proteid is that it is very essential to the formation of fibrin during coagulation. It is formed by the dissolution of the leucocytes and blood-plates after the blood is shed from the body. When hydrocele, pericardial, and ascitic fluids contain no leucocytes, it has been noticed that they lack power of spontaneous coagulation. The nucleo-proteids in the presence of calcium salts form a substance which is identical in every respect with the *fibrin-ferment* of Alexander Schmidt. This new substance possesses the power of converting fibrinogen into fibrin.

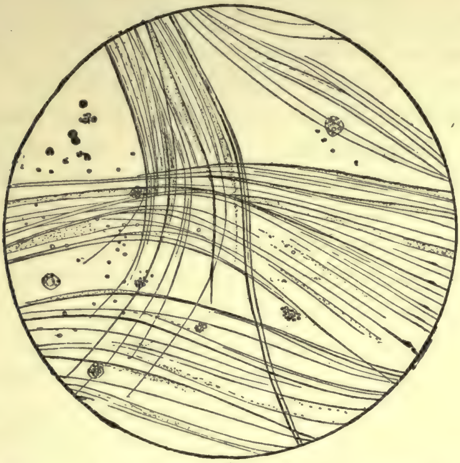


Fig. 61.—Delicate Fibrin Coagulum (from Croupous Pneumonia.) × 350. (Lenhartz.)

THE NONPROTEIDS OF THE PLASMA.—The nonproteids comprise both *nitrogenous* and *nonnitrogenous* elements.

The *nonnitrogenous* consist of carbohydrates and fats, with small amounts of lipochrome and sarcolactic acid.

The *nitrogenous* elements comprise in their category urea, uric acid, hippuric acid, creatin, and some ferments.

Urea, which represents the end-product of nitrogenous combustion of the tissues must be included among the normal elements of this fluid. It is found in the blood in small proportion. But it can accumulate in an abnormal manner within the blood. It is in this way that ablation of the kidneys, acute nephritis, and the terminal feverish period of cholera, in which the urinary secretion is suppressed, provoke the accumulation of urea in the blood.

Gases.—Oxygen, carbon dioxide and nitrogen are present. The oxygen is united to the hæmoglobin of the red corpuscle.

The combinations of carbonic acid in the blood are much more complex than those of oxygen. In 100 cubic centimeters of arterial blood carbonic acid is associated as follows:—

1 to 2 cubic centimeters of CO_2 dissolved in plasma.

35 to 40 cubic centimeters of CO_2 in combination in plasma.

10 cubic centimeters of CO_2 in the corpuscles.

Carbonic acid dissolved in the plasma exists in a state of carbonate and bicarbonate, in the red corpuscles in a state of phosphocarbonate of sodium and carbo-hæmoglobin.

The nitrogen is simply dissolved in the plasma.

Blood-serum.—Blood-serum is blood-plasma minus fibrinogen. Serum contains serum-globulin, serum-albumin and fibrin-ferment (nucleo-proteid.) Serum is a liquid, slightly viscid, of a yellow color, or may be milk-like in color if the diet has been rich in fat, due to the presence in it of fat, and has a saline taste. The amount of serum is a third or a half of the whole quantity of blood. The substances in the serum, like in the plasma, are sodium and potassium chloride, potassium sulphate, sodium and calcium phosphates, magnesium phosphate and sodium carbonate. The chief salt of these is sodium chloride, forming nearly one-half of the inorganic salts. The quantity of salt is about 8 parts in a 1000. The quantity of sodium chloride in the blood is very constant. In animals deprived of sodium chloride the proportion of salt in the blood diminishes very little. The kidneys excrete very little. If, however, a large amount of salt is taken it is rapidly eliminated by the kidneys. The importance of having a fixed amount of sodium chloride always in the blood is the necessity to preserve the osmotic pressure.

The Serum-albumin and Serum-globulin of Serum.—They have the general characteristics of the albumins and globulins. In starvation the quantity of serum-albumin diminishes, that of serum-globulin increases. Besides these bodies there is also found a small quantity of nucleo-proteid in the serum:—

Sugar.—One part in a 1000 is also found here.

Fat.—The quantity of fat in the blood varies very much. It swings between 1 to 7 parts in a 1000 in the dog. The fatty matters are neutral fats, soaps and lecithin. The fat acids are found in combination with cholesterin; glycerin normally exists in the blood, 0.001 parts in a 1000.

The Coloring Matter.—The serum is colored yellow by a body which belongs to the luteine group, and is often called lipochrome or seroluteine.

Enzymes.—There are several ferments, as lipase, anti-ferments; also alexins, hæmolysins, precipitins, etc.

Lactic acid is also found, which is, in part, dependent upon meat in the diet. Its quantity varies from 0.17 per cent. to 0.5 per cent.

COAGULATION OF THE BLOOD.

Normal blood contained within the body vessels is a fluid. For a very brief period after it makes its exit from a wounded vessel it remains in a liquid state, but within two or three minutes its viscidity increases until there is formed a solid of the consistency of jelly; to this has been given the name *blood-clot.* The process whereby the clot is formed is termed *coagulation,* and is caused by the presence of a body called *fibrin.*

To best observe the process of coagulation, the blood is drawn into an open vessel, a beaker. The initial change, which occurs within the first two or three minutes, is the formation of a jelly-like layer over the surface of the blood; during the next three or four minutes this layer extends to such a degree that the entire blood-mass becomes enveloped. If at this time the contents of the vessel be turned out, they form a mold of the exact shape of the containing vessel, or the vessel may be inverted without the escape of the contents. This jelly-like mass is the clot. Within it are imprisoned the serum and corpuscles.

A straw-colored fluid, the *serum,* is expressed, appearing upon the surface to form finally a transparent layer of liquid around the clot. The retraction is complete at the end of from twelve to twenty hours, at which time all of the serum has been expressed and the corpuscles enmeshed within the network of fibrin. The clot, so dense that it may readily be cut with a knife, being heavier than the serum, is found at the bottom of the vessel. It is now just about one-half of its original size. The serum, when examined, is found to be practically free from corpuscles. The character of the clot varies according to the state of the blood. It is large, soft, and tears easily at times. At other times it is small, resistant, and from the energetic contraction of the fibrin the edges of the upper surface of the clot curve over so as to form a sort of cup.

The clotting of the blood is due to the development in it of *fibrin*, whose fibrils arrange themselves in the form of a network.

In blood within its vessels there are found no such fibrils of fibrin; therefore normally no coagulation occurs within the body. These fibrils then must have been formed by some change, chemical or otherwise, of one or more constituents of the blood. That the corpuscles themselves cannot form a clot excludes them, so that our attention is turned to the plasma. In it is formed the fibrin, for pure plasma from which the corpuscles have been removed very readily coagulates. When blood is vigorously beaten with twigs, long shreds of a nearly transparent substance are found adhering to them. These are fibrin-fibers, free, or nearly so, from corpuscles. Its structure consists of very delicate, doubly-refractive fibrils of microscopical size.

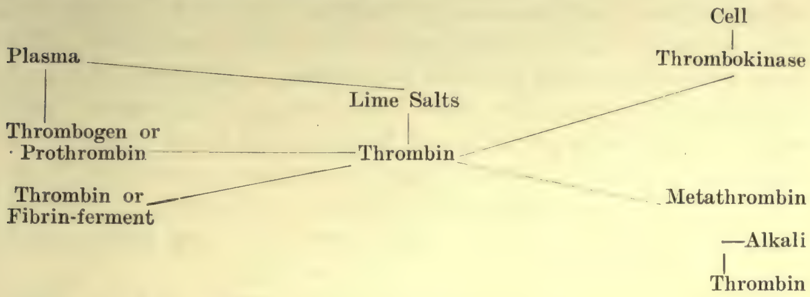
Many theories have been propounded to account for the formation of fibrin and the coagulation of the blood, but the one most widely received is that of Hammersten, a Swedish investigator.

In the study of plasma it was learned that one of its constituents was a proteid of the globulin class, to which had been given the name fibrinogen. It is held in solution by the plasma and is believed to be an end-product of the disintegration of useless white corpuscles. Within the circulating fluid there is an immense number of these white cells; when blood is withdrawn from the living vessel there is a large and very sudden destruction of them; according to Alexander Schmidt, 71.7 per cent. are dissolved. When these little bodies are disintegrated in the laboratory they yield nucleo-proteids; so that it is very probable that practically the same products result upon disintegration in the shed blood. To this nucleo-proteid has been given the name *prothrombin.* By the action of the *calcium salts* dissolved in the blood-plasma the prothrombin is converted into *fibrin-ferment,* or *thrombin.* When thrombin comes into contact with the fibrinogen molecule dissolved in the plasma it splits it into two parts: one is a *globulin,* which is very small in proportion and equally unimportant; it remains in solution. The other is the insoluble substance *fibrin,* which entangles the corpuscles and is so essential to the formation of the blood-clot.

To epitomize, it may be said that coagulation depends upon *three factors,* according to Hammersten's theory: (1) *calcium salts* to convert the nucleo-proteids in the form of prothrombin into *thrombin,* or (2) *fibrin-ferment;* this latter breaks up the (3) *fibrinogen* in solution into an unimportant globulin and the all-important fibrin.

Fibrin-ferment is a term used simply for convenience and probably is a misnomer. It is a proteid of the globulin group whose substance does not seem to be used up in the process nor to enter into the fibrin formed; a small quantity of it serves to break up an immense amount of fibrinogen.

Calcium is needed only in the formation of fibrin-ferment, and is not needed for the action of the fibrin-ferment on fibrinogen. This is shown in the schema below.



This schema gives the method of the formation of thrombin or fibrin-ferment according to Morawitz. The active substance in the tissues is thrombokinase. Thrombogen is assumed to exist in circulating blood, and is formed from the blood-plates and the white corpuscles. The pre-existence of thrombogen in blood is shown by the venous injection of the juices of tissues producing coagulation. Thrombokinase is intra- and extra-vascular, and is formed from the white corpuscles. Thrombokinase can be obtained from all tissues as a general protoplasmic product, whilst thrombogen is not found in the tissues. Thrombokinase is thermolabile, but stands more heat than fibrin-ferment. It is easily destroyed by autolysis and alcohol. In the plasma of the circulating blood is found all the necessary factors for coagulation, fibrinogen, lime salts and thrombogen; the only thing wanting is thrombokinase. Thrombokinase comes from the extra-vascular formed elements of the blood, which by contact with foreign bodies gives the thrombokinase to the plasma. If blood is received under oil or in a paraffined glass, then it remains fluid for a long time, since no adhesions and no irritant by a foreign body acts upon the formed elements.

When blood flows from a cut it rapidly clots, owing to the thrombokinase supplied by those tissues over which it runs.

The formation of an active fibrin-ferment from the action of thrombogen, thrombokinase and lime salts cannot be chemically defined. It is not known if the thrombokinase acts quantitatively or by a ferment action. By coagulation the whole thrombogen material is not used up, for you can find it in the serum, which becomes active by adding the juice of tissues. The greater part of the formed thrombin soon passes into an inactive form, metathrombin, but by alkali or acids can again be changed in thrombin.

The Importance of the Lime Salts in the Formation of the Fibrin-ferment.—It was found by Arthus and Pages that if the lime salts were rendered insoluble by oxalates, the blood did not clot. The addition of calcium salts makes the oxalate-plasma clot. Calcium fluoride or citrate acts like the oxalate. This showed that the presence of soluble calcium salts is necessary. Hammersten found out that calcium is not necessary in the second stage of the act of coagulation. It is in the first stage, in the formation of the fibrin-ferment, that the presence of a soluble calcium salt is involved. Pekelharing and Hammersten have shown that the calcium salts activate a pro-thrombin present in the plasma.

The Action of the Injection of Fibrin-ferment and the Tissue Juices Into the Blood.—As a rule, fibrin-ferment from the serum causes intra-vascular clotting, deadly thrombi. The organism, however, has the power to make small quantities of the fibrin-ferment inactive.

The juices of tissues, tissue extracts, often cause in rather small doses extensive intra-vascular clots, which chiefly originate in the right heart.

In that peculiar hereditary disease of males only, hæmophilia, there is a want of coagulation. Morawitz and Lossen found in blood drawn from the veins of a hæmophilic that it took two hours to clot, that the addition of calcium chloride did not accelerate coagulation, that fibrinogen was normal in amount, and that the addition of thrombokinase clotted the blood like it does normal blood in one minute. The serum of the hæmophilic contains more fibrin-ferment than normally exists. Hence, the trouble in these cases seems to be a want of thrombokinase.

A condition known as *buffy coat* occurs when blood coagulates *very slowly.* It is most readily seen in horses' blood, being caused by the more rapid sinking of the red corpuscles in slow coagulation, thus leaving the upper stratum to consist of a layer of fibrin and white corpuscles. This whitish layer is elastic, has some resistance, is more or less opaque, and has therefore been designated the buffy coat.

The *shape of the vessel* is also a factor in the production of "buffy coat." If the vessel be long and straight, the fall of the corpuscles is facilitated. The buffy coat then appears. No buffiness, however, is seen if the vessel be large and low, and if the blood be received in a vessel which is *shaken* from time to time. The blood of different parts of the vascular system shows differences as to the time required for complete coagulation. Arterial blood coagulates more quickly than venous; blood of the hepatic veins coagulates very little, and the same is true of menstrual blood—probably due in the latter to mixture with the alkaline vaginal secretions, for, when menstruation is so abundant that this alkalinity is overcome, then clotting may ensue.

Fibrinogen.—This body pre-exists in circulating plasma. The most recent experiments show that the liver is the place of origin of fibrinogen, and many believe the myeloid tissue of the medulla of the bones also participate in its formation. By different injuries to the liver the fibrinogen disappears from the blood. The same result ensues from poisoning by phosphorus and by chloroform, after the injection of hepatotoxic serum, and after the exclusion of the liver by Eck's fistula. After the arrest of the abdominal circulation the fibrinogen disappears in the blood of the anterior part of the animal. In most diseases with leucocytosis, also in irritation of the medulla of bones, there is an hyperinosis, an increase of fibrinogen in the plasma. But there is a direct relation between the number of leucocytes in the circulating blood and the quantity of fibrinogen.

With pneumococcus infection, according to Langstern and Mayer, the formation of a leucocytosis is often attended with a great increase of fibrinogen.

The Change of Fibrinogen into Fibrin.—It is supposed by Hammersten that the thrombin causes a splitting of the fibrinogen molecule, with the formation of an insoluble fibrin and a soluble fibringlobulin. The majority of observers do not believe in the splitting of fibrinogen as held by Hammersten, but in a molecular change of the fibrinogen.

Agents which Retard Coagulation.—Neutral salts, like concentrated solution of magnesium sulphate, sodium sulphate and sodium chloride, retard coagulation. These salts retard the action of the formed thrombin. Strong refrigeration acts in a similiar way. Bile salts, in a much less concentrated solution than the neutral salts, retard coagulation. The bile salts seem to do this in a way similar to that of the neutral salts. Calcium chloride is often given for some time previous to operation on the gall-bladder, where there has been much jaundice, to prevent the hæmorrhages which may ensue on account of hindrances to coagulation by the long action of the bile on the blood.

Agents are found in the blood-plasma and serum which retard coagulation in the oxalate-plasma and in the sodium fluoride-plasma. Also in serum there are bodies hindering coagulation, although the serum contains thrombin. Normal serum inhibits the action of strong active fibrin-ferment. It must then be inferred that in circulating normal blood there are substances which tend to inhibit coagulation, antithrombins. There are bodies which act in a direct manner to inhibit coagulation, like snake venom and hirudin, the latter coming from the salivary glands of the leech. Hirudin has chemical peculiarities like a secondary albumose, loses its powers completely or in part by heating at 100° C., and dialyzes with difficulty. This leech product acts intravascular and extravascular, and is the best means in the physiological laboratory to prevent the clotting of blood.

This substance is supposed to be antithrombin, and thus prevents the clotting of blood.

In snake venoms, especially in that of the cobra, there is a body which, in very small doses (0.00001 gram to each kilogram of the animal), hinders coagulation in the body and in vitro. Its action against the formed thrombin is less than against the formation of thrombin. Peptone injections per vein and other bodies of the peptone group retard coagulation. This action has been ascribed to the mixture with proteoses. If the liver is excluded, peptone fails in preventing coagulation; hence the liver plays the most important part in the retardation of coagulation by peptone. An antithrombin exists in healthy blood to prevent clotting in the blood-vessels, and is formed in the liver. The proteoses stimulate the liver to produce an excess of antithrombin in the blood and the peptones in this way prevent the clotting of blood. The serum of certain Italian eels also prevents coagulation.

Mellanby states that the negative phase of blood in coagulation owes its fluidity to the absence of fibrinogen, cobra blood to the presence of an antikinase not to an antifibrin-ferment, peptone blood to the presence of an excess of alkali excreted by the liver stimulated by the injected peptone, and hirudin blood to the presence of an antikinase and an antiferment.

The saturation of blood with CO_2 (thus in asphyxia the blood does not coagulate). Blood received into a vessel filled with *oil* does not coagulate. Coagulation is prevented when the blood is in contact with normal, living, vascular walls. The addition of certain articles retards coagulation; thus, feeble doses of alkalies, carbonate of sodium and potassium, sugar, water and albumin. In lightning strokes, the blood does not coagulate.

Agents Accelerating Coagulation.—I have alluded to the action of calcium salts in the different acts of coagulation.

1. The internal use of calcium chloride or calcium lactate shortens the time of coagulation. Gelatin also accelerates coagulation, which has been ascribed by Gley to the lime salts in the gelatin. 2. A temperature a little higher than that of the body (102° to 107° F.). 3. Presence of foreign bodies. If a needle be made to penetrate the wall of a vessel, fibrin is deposited upon it and so produces coagulation. It seems to be a sort of phenomenon analogous to that which occurs when a thread is suspended in a solution of sugar, when the crystals of sugar are deposited upon it. Injections of laky blood accelerate coagulation.

The Acceleration of Coagulation by Tissue Substances.—It has been known for a long time that not only in the blood-serum, but also in the different cellular elements of the organism, there was a substance which accelerated coagulation. It was known by the name of cell-globulin, cell-fibrinogen, nucleo-proteid of tissue, etc. Pekelharing showed that this body in the tissues acted like fibrin-ferment. According to Schmidt, this body is a zymoplastic substance. Its nature is at present unknown.

Fuld and Spiro from experiments upon the action of tissue extract upon the plasma of the goose conclude that the acceleration of coagulation increases with the square root of the quantity of extract, which corresponds to the Schütz-Borrisow law for ferments, and makes the action of thrombin like a ferment.

Pathological Action.—If the wall of a blood-vessel becomes diseased, as in atheroma, it loses the power to prevent clotting, and a clot may form.

Why Blood does not Normally Coagulate within the Blood-vessels.—Much time and experiment have been given to ascertaining the cause for noncoagulation within living walls, but notwithstanding the question is yet unsettled. By some it is thought that the destruction of the white corpuscles is not extensive enough to furnish the proper supply of nucleo-proteid, from which fibrin-ferment is manufactured. According to Schmidt, the blood within the living vessels is constantly being acted upon by two opposing influences: one with a tendency to promote coagulation, the other to oppose it—antithrombin. In health the former never gains the ascendency.

Hæmorrhage and its Effects.—It is common knowledge that a very abundant loss of blood causes death. The blood has for its functions to insure the physical conditions of the life of the cells as well as to maintain an excitability of the nerve-cells which govern respiration and circulation. Every considerable loss of blood disorders cell-life in the organism, tending to cause death. Necrosis very soon manifests itself when a member has by some procedure been deprived of its normal supply of blood. When the loss of blood has been from the whole system, and not confined to any member, a general death precedes the local death of the cells, because, the oxygen not going to the cardiac and respiratory centers, the functions of the heart and lungs are arrested. The principal symptoms of great loss of this vital fluid are general paleness and lower temperature of the cutaneous surface, oppression, breathlessness, stoppage of the secretions, with final general convulsions of anæmia.

The *quantity* of blood which can be lost without causing death varies according to age, sex, temperature, etc. The loss of some cubic centimeters in the newborn, of a half-pound in an infant of one year, or of half the quantity of blood in an adult, is capable of causing death. Women bear the loss of blood much better than men because of the periodical hæmorrhages to which they are subject.

The renewal of the blood appears to be accomplished rapidly, although the *time* of withdrawal plays an important rôle in determining whether there will be attending fatality. If the loss has not been too rapid, the fluid part of the blood and its dissolved salts is replenished by withdrawal from the lymph of the tissues. Later the albumin is restored, but a much longer period is required for replenishment of the corpuscles. The amount of hæmoglobin is diminished in proportion to the amount of bleeding.

SHOCK very materially affects the results of hæmorrhage. When the sensibilities are deadened temporarily by anæsthetics, less serious results follow the loss of a given quantity of blood than when the same quantity escapes through accident.

TRANSFUSION.—This is a process by which blood is conveyed from one animal to the vascular system of another. It was shortly after Harvey's discovery of the circulation of the blood that this operation was first practiced by Denis, of Paris. He transfused with success the blood of a lamb into that of a man. It was believed that a great panacea had been discovered whereby not only blood lost by hæmorrhage could be replaced, but a cure effected for many diseases and infirmities. Subsequent attempts proved such miserable failures that the operation was abandoned and even proscribed by law. More than a century later it was revived, but only after much experimentation upon the lower animals.

The serum of certain animals possesses the property of dissolving the red corpuscles of another species of animals. The serum of a dog destroys the red corpuscles of man; the hæmoglobin is dissolved out. The serum, besides its action on the red corpuscles, is also active against the white corpuscles of the same animal, stopping their amœboid movements. The hæmolytic action of the serum is related to its poisonous action on microbes. The normal serum of certain animals kills microbes, as the serum of the dog kills the typhoid bacilli. The power to kill red corpuscles and microbes is due to the presence in the serum of two substances, an alexin or complement and an amboceptor. In transfusion this plays an important part.

The knowledge gained thereby was to the effect that, for the operation to be at all successfully performed, blood of the *same species* of *animal* should be used as the one on which it is performed. It was only after the establishment of this rule that it appeared possible to determine the value of transfusion and to make application of it, with some degree of safety, to man.

In practice there are two kinds of transfusion: (1) blood with fibrin; (2) blood without fibrin. In using fibrinated blood the stream is passed directly from the blood-vessel, either artery or vein, into that of the patient. Usually the peripheral end of a vein of the person furnishing the blood is united with the central end of a vein of the patient. The tubing should have been previously filled with a normal salt solution so as to exclude the entrance of air into the circulation, for, if sufficient quantity of it be introduced, it will be carried to the right side of the heart, where, by virtue of the heart's action, a froth will be generated, the bubbles from which, being pumped into the pulmonary arteries, arrest pulmonary circulation and cause death. The danger of coagulation is, however, very great.

In using defibrinated blood the shed blood is first whipped in an open vessel with a glass rod so as to separate the fibrin; it is then filtered, heated to the temperature of the body, and injected very slowly into a vein (usually the median basilic) in the direction of the heart. Besides giving a tendency toward intravascular coagulation, there is also danger of introduction of bacteria, whose entrance into the injected blood occurs with the beating in the process of defibrination.

It has been learned that the most serious symptoms of rapid hæmorrhage follow the *sudden* diminution in the amount of blood in circulation, accompanied with a moderate *fall of blood-pressure.* From these data we conclude that the proper measures to take are to replenish the *amount* of *fluid* regardless of the corpuscles or the soluble nutrient elements of the plasma. A precaution to be taken is that the fluid should be of such a density and nature that no disturbance in the vascular system be generated.

This knowledge has led to the manufacture of various artificial solutions for infusion, the one most used being a warm, sterilized, physiological salt-solution (NaCl, 0.75 per cent.); this is injected either subcutaneously or into any exposed vein.

Transfusion is called for after *copious hæmorrhage* (acute anæmia), or in cases of *poisoning* when the blood-corpuscles are no longer capable of supplying the tissues with their required supply of oxygen. This condition is particularly prominent in carbon-monoxide (CO) poisoning.

Plethora.—The old physicians admitted that there was in certain individuals of sanguine temperament an exaggerated richness of the mass of blood as a consequence of too active nutrition. However, it is impossible to verify in an experimental manner if the mass of blood be augmented. Yet plethora is usually accompanied with a swelling of the veins and arteries; an injection of mucous membrane; a full, hard pulse; congestive vertigo, and dyspnœa from pulmonary congestion. Many physicians believe that there is no such condition as too much blood in the body, unless it be introduced experimentally by transfusion. The above symptoms are explained by reason of an increased peripheral circulation at the expense of the more central one. Nevertheless, the above-named symptoms disappear by blood-letting, which would seem to admit the existence of plethora to a certain extent.

An experimental plethora may be induced in dogs by transfusion; so that the blood may be increased from 80 to 100 per cent. without provoking any trouble. The injected plasma is soon gotten rid of, but the surplus corpuscles remain for a long time. There is also believed to be an increase in the number of red corpuscles in those persons in whom for any reason there should be a suppression of periodically recurring hæmorrhages, as in menstruation and bleeding from the nose.

Plethora of water, or *hydræmia*, follows the excessive ingestion of water. The condition is but temporary, however, as an increased diuresis rapidly eliminates the excess of water.

Function of the Blood.—Nourishment is carried to the tissues and waste from them by the blood. The sameness of the blood in chemical composition must always be maintained. During digestion the white corpuscles increase, but they soon return to their original number, the excess of corpuscles being retained in the lymphatic tissues. The tissues themselves keep the composition of the blood constant. If some potassium ferrocyanide is injected by the vein into a dog whose ureters have been previously tied, at the end of three hours there is only a small quantity in the blood, and at the end of twenty-four hours only a trace of it. The ferrocyanide has passed into the tissues. Any disease of the kidneys at once leads to changes in the molecular composition of the blood. The red corpuscles carry oxygen to the tissues. The plasma conveys the carbonic acid combined with sodium to the lungs. The white corpuscles furnish the fibrin-ferment, lysins and complements.

MEDICO-LEGAL TESTS OF THE BLOOD.

To determine that a substance under examination and inspection is blood several tests are employed:—

First.—Teichmann's crystals, or hæmin crystals, are a product of decomposition of the coloring matter of the blood. They may be prepared by the addition to the blood of glacial acetic acid and sodium chloride. A few granules of dried blood with a few granules of salt are pulverized on a glass slide; having covered the powder with a glass circle, a drop of the acid is allowed to flow under, when the slide is heated. If the examined substance be blood, the characteristic crystals appear.

Second.—The Guaiacum Test.—On treating a solution of the coloring matter of the blood with an alcoholic tincture of guaiacum and an ethereal solution of hydrogen peroxide, a deep-blue coloration is produced, due to oxidation of the guaiacum resin.

Third.—The Spectroscope Test, in which characteristic bands appear.

Fourth.—Careful measurements of the blood-corpuscles, their diameter, etc., by means of the microscope and photomicrographs.

Fifth.—THE PRECIPITIN TEST.—Strong rabbits are injected subcutaneously with 5 cubic centimeters of sterile human blood, the injections being repeated every two or five days, depending upon the condition of the test animal. The occurrence of a rise of temperature above 101° F. or a decided loss in weight are considered counter-indications to further injections until after this reaction has subsided. It is better to give injections of only 5 cubic centimeters each and always with great care as to asepsis, since abscesses often develop at or near the site of puncture. Usually 20 to 30 cubic centimeters make a sufficient quantity for the average-sized rabbit, and with due care a specific anti-serum can always be produced in from three to four weeks. After a sufficient quantity of blood has been injected to insure obtaining an anti-serum, the rabbit is chloroformed, the chest-cavity opened, and the blood drawn from the heart into a sterile receptacle by means of a sterile trocar and cannula. The drawn blood is placed in an icebox for one hour until well coagulated. Carbolic acid is now added to the serum, which has separated sufficiently to make the mixture approximately 0.5 per cent. acid. The serum is then drawn up into sterile pipettes and sealed. It will remain potent indefinitely if kept at a low temperature.

The test is made as follows: A given amount of the test-serum is diluted to the desired extent with sterile water or normal saline solution. To a few cubic centimeters of this diluted solution in a sterile test-tube is added an equal quantity of a similarly diluted solution of the blood to be tested and the tube left at room temperature or placed in an incubator for two or three hours at 37° C. The reaction, if it occurs, will be more rapid and marked if the tube is exposed to the higher temperature. If the dilution be sufficient the reaction will not occur at room temperature. If the test-serum is used undiluted and pure human blood is added to it, the reaction is immediate.

If only the sample of blood to be tested is diluted and pure test-serum is used, the reaction is almost immediate. The reaction is marked by a turbidity of the solution, becoming constantly more intense. If an old stain is to be examined by the serum test the material containing it is washed in sterile water or in sterile normal saline, the mixture is repeatedly filtered and finally added to some of the test-serum, as in the examination of fresh blood already described.

Contamination with monkey blood can be excluded first by a great dilution of the blood tested, and a dilution of the test-serum of 1 to 500, with incubation; second, by a great dilution of the blood tested, the test-serum being used pure and the test made at room temperature.

IMMUNITY.

Normal sera may contain:—

1. Antiferments (blood-serum prevents the ferments from acting as trypsin on proteids or a mixture of pancreatic juice and enterokinase, because the kinase is neutralized).
2. Antitoxins.
3. Cytotoxins (cell-destroyers include hæmolysins. These bodies are composed of complement and an immune body or amboceptor).
4. Agglutinins.
5. Precipitins.

ZYMOIDS.[1]

There are a certain number of substances contained in the cultures of microbes which may be in the liquids of the organism, and notably in the blood-serum of normal animals and in animals vaccinated against certain microbes or their filtered cultures, *which have, with the ferments, a certain number of common properties.* Such bodies are the microbian toxins, the venoms of serpents, the antitoxins, the agglutinins, the precipitins, the bacteriolysins, the hæmolysins, etc. Because of certain analogies to enzymes, they have been called enzymoids. Toxins are the nonalkaloidal poisons produced by microbes or secreted by the animal or vegetable cell. These toxins are divided into two kinds: (1) the toxalbumins, cellular secretions destroyed by heat at 70° C., but not coagulating; they do not act except after a period of incubation, always long, as the toxins of diphtheria, of tetanus, etc.; (2) the toxproteins, derived from cells coagulating by heat, acting upon the organism, and acting without a period of incubation; these are the venoms, the proteins of plague and cholera. We have also vegetable toxalbumins, as abrin from jequirity, ricin from castor-oil seeds, rubin from the extract of the bark of the acacias. These bodies are zymoids. The toxalbumins always have a period of incubation. The phenomena shown are all physiological phenomena; an infinitely small quantity of toxalbumin is able to cause phenomena infinitely great. We should remember that certain microbian products, as tuberculin or mullein, resist the prolonged action of 100° C. without alteration.

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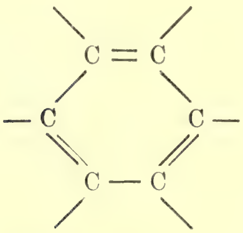
[1] In the preparation of this article I have drawn on Arthus, "Chemie Physiologique."

The toxalbumins and venoms have other common biological properties.

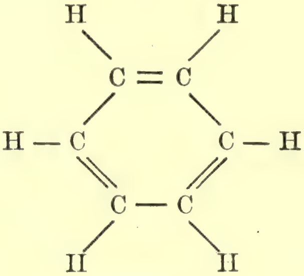
ANTITOXINS.

It is possible, by repeated injections of toxalbumins or venoms in increasing doses, to immunize the animal against the toxic action of doses, a thousand times mortal, of the toxalbumin or venom. The immune animals furnish an antitoxic serum. The toxalbumins or venoms when swallowed are harmless; injected under the skin, very active. Like the ferments, the toxins are destroyed by a relative low temperature, about 70° C. They are precipitated by alcohol, and they dialyze with difficulty. If in a test-tube you mix the toxin and the antitoxic serum in proper proportions, the mixture is harmless to the animal when injected, but this countereffect requires a certain time for its accomplishment. These facts show that the antitoxins resemble ferments; that is, they are soluble, precipitable, and dialyze like enzymes, but are not enzymes. The basis of Ehrlich's theory is that poison and counterpoison, toxin and antitoxin, directly combine in any given quantity.

The stable benzene ring and the less stable side-chains of the benzene derivatives suggested to Ehrlich that living cells also consist of a stable center and less stable side-chains. The side-chains enable the cell to form chemical combinations with foodstuffs and other bodies that have atom groups having a chemical affinity with the atom groups in the side-chains.



Benzene nucleus or ring.



Benzene.

Ehrlich showed further that for each poison one can develop a counterpoison by the process of immunizing, which has two groups which are concerned in the combination with the counterpoison or antitoxin. One of these, the haptophore group, is the combining group proper; the other, the toxophore group, is the carrier of the poison. A poison molecule might lose the one, the toxophore group, and still be capable, by means of its haptophore group, of combining with antitoxin. For a poison to be toxic to an organism—that is, in order that the toxophore group be able to act destructively on a cell—it is necessary for the haptophore group of the poison to combine with the cell. The side-chains are able to combine with the greatest variety of foreign substances and convert them into nourishment suitable to the requirements of the active central body. These side-chains are comparable to the pseudopodia of the amœba which engulf food particles and assimilate the same for the immediate use of the organism. In order that any substance may combine with these side-chains, it is necessary that certain very definite relations exist between the combining group of the substance and that of the side-chain. The relation must be that of lock and key; that is, the two groups must fit accurately.

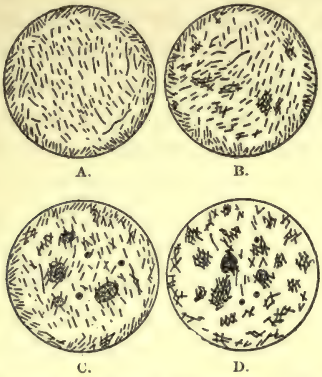


Fig. 61a.—Stages in Widal Reaction. (After ROBIN.)

AGGLUTININS.

If we cultivate a vibrio of cholera upon gelatin, and after twenty-four hours put the culture in a saline solution 1 to 100, we obtain a homogeneous and stable emulsion, in which the vibrios retain their activity. If to this emulsion we add a small quantity of blood-serum (of a rabbit or guinea-pig) strongly immunized against the vibrio of the emulsion by the intra-peritoneal injection, we will see under the microscope that the vibrios lose their mobility and unite in masses of greater or less size, agglutinate, so to speak. This agglutination augments until the mass becomes voluminous. This agglutination is not a necessary result of the vitality of the vibrios; it is just as easily produced with emulsions of dead vibrios.

The agglutinating serum acts most energetically at 55 or 60° C. The active substance in the serum is precipitated by alcohol, it is not destroyed by drying at a low temperature, and it dissolves in water and glycerin. These are the properties also of enzymes. The active substance here is agglutinin. *Widal Reaction.*—The typhoid patient's serum gives an agglutinating serum for homogeneous cultures of the typhoid bacillus.

PRECIPITINS—TSCHISTOVITCH-UHLENHUTH TEST.

When you inject under the skin or into the peritoneum of an animal *a*, of species *A*, some cubic centimeters of blood-serum of species *B*, and repeat the injection four or five times in the space of five or six days, we find that blood-serum of the animal *a* has the property, when mixed with the serum of the animal of species *B*, to cause a fine precipitate at the bottom of the mixture. If in place of the injection of blood-serum, under the same conditions we inject the albuminoid substances of the serum separated by precipitation by ammonium sulphate and dissolved in saline 1 to 100, we find that the serum of *a* has acquired the property of precipitating the serum of the animal of the species *B* as before. This fact is used to determine human blood by injecting the serum of human blood into rabbits or dogs. We thus obtain precipitants for human blood, a medico-legal test. This precipitate is destroyed by heat over 100° C.; it is not destroyed by drying at a low temperature; it is soluble in water; it is precipitated by alcohol and by the salts precipitating globulins. These are the properties of enzymes. It may be a zymoid.

CYTOTOXINS.

As to cytotoxins, we have seen in transfusion that blood foreign to an animal dissolves its corpuscles (or cells); hence are called hæmolysins. The leucotoxins dissolve white blood-corpuscles. The hæmolysins act by separating the hæmoglobin from the stroma of the blood-corpuscles, making blood "laky." In fundamental characters the hæmolysins, both natural and artificial, correspond to the bacteriolysins.

If you introduce into the peritoneal cavity of a guinea-pig, which is strongly immunized against a vibrio of cholera, an emulsion of this vibrio obtained by putting into a saline solution, 1 to 100, a 24-hour culture of the cholera vibrio upon gelatin, it will be found, on withdrawing a little of the peritoneal fluid, after half an hour, that the vibrios injected have lost their motion, are transformed into lumps, and are broken up into granules. This is known as the phenomenon of Pfeiffer. This property of the serum of a vaccinated animal is due to the presence of a substance, a bacteriolysin, or lysin, or cytolysin; the complement and the intermediary body make up the cytolysin.

It has been demonstrated that the bacteriolytic cholera-serum contains two distinct substances, acting one after the other in the bacteriolysis, one substance destroyed below 60° C. and existing in normal serum as well as in cholera-serum, and another substance resisting a temperature of 60° C. and not existing except in the cholera-serum. The specific substance has been called a thermostable substance, because it resists a temperature of 60° C.; and a sensitizing substance, because it renders the microbe sensitive to the action of normal serum; also an immunizing substance or mediator, sensitizer, amboceptor, intermediary body, because it exists in the serum of animals immunized against the microbe. The common substance contained in the normal serum has been called a thermolabile substance, because it is destroyed at 60° C.; and because it completes the action of immunizing, it is known as a complementary substance, complement, or alexine, or cytase.

We have seen, in injecting an animal *a* of species *A*, that the red blood-corpuscles coming from the animal of another species, *B*, will cause a specific agglutinin to appear in the serum of the animal injected, *a*. But there appears at the same time also a hæmolysin. After having agglutinated the red corpuscles of an animal of the species *B*, the serum of the animal *a* dissolves them, or, to speak more exactly, breaks the union of their stroma with their hæmoglobin, and the latter passes in solution into the surrounding fluid. It has been shown that hæmolysin is specific and does not act except on the red corpuscles of the species *B*, which has served for the preparatory injections. It has been found that hæmolysis, like bacteriolysis, is accomplished in two periods of time; that the hæmolysins, like the bacteriolysins, are formed of two substances, an intermediary body or amboceptor, and a complement or alexin. The specific substance is amboceptor, the alexin is the same common complement or alexin which acts upon the various sensitized bacteria. Take an illustration in which the characters are reversed. We may regard the pepsin in artificial digestion as the amboceptor, and the acid as the complement. The pepsin or amboceptor occurs only in immune serum, while the acid, which may be hydrochloric or phosphoric, corresponds to the complement found in a variety of serums.

The lock and key simile of E. Fischer affords perhaps the best analogy. The lock is the cell, the key is the amboceptor, and the hand which turns the key is the complement. The macrophages attack the xanthocytes, or large animal cells, and malarial parasites. The microphages prefer the bacteria of acute diseases. The complement occurs in normal animals, the amboceptor is developed.

Hæmolysins are derived from the leucocytes. Bacteriolysins are contained in the euglobulin fraction of the serum.

Enterokinase acts like an amboceptor, uniting the red corpuscles of the blood to trypsinogen, which behaves like a complement and dissolves the red blood-corpuscles.

The toxic action of cobra-poison upon red blood-corpuscles depends upon the combination of amboceptors, intermediary bodies contained in the venom, with corresponding complements contained, not in the venom, but in the cells or fluids of the animal acted upon. Kyes, working with cobra-venom found an endo complement contained in the red corpuscles themselves. Kyes also found that lecithin is capable of combining with venom intermediary and thus completing the hæmolytic potency of venom. Here is a cytotoxin formed of an intermediary body and a definite crystallizable substance uniting with it, thus acting as a complement. Here we have a poison in our own body, only needing the intermediary body of the venom to act upon us. Snake-poison only contains one-half of the complete poison. Rattlesnake-poison has been found by Flexner and Noguchi also to contain another cytotoxin which has the power to dissolve endothelial cells, an endotheliallysin.

It is an important function of the mother to transfer to the suckling, through her milk, immunizing bodies, and the infant's stomach has the capacity, which is afterwards lost, of absorbing these substances in the active state. The relative richness of the suckling's blood in protective antibodies, as contrasted with the artificially fed infant, explains the greater freedom of the former from infectious disease.

OPSONINS.

There is in normal serum a substance which so acts upon bacteria as to render them susceptible of being devoured by the leucocytes. In some way serum stimulates phagocytosis by making the bacteria more susceptible of being absorbed by leucocytes. This substance in the serum has been denominated by Wright and Douglass, opsonin (feast-preparer).

CHAPTER VI.

THE CIRCULATION.

In animals above the very lowest grades, as also in plants, there exists a particular liquid (nutritive fluid, blood, sap), which is agitated into a circular or simply oscillating movement. By reason of this movement it is permitted to reconstitute itself unceasingly, to distribute the materials of nutrition to the different parts of the organism, and at the same time carry away some effete products.

In the lowest orders of animal life, as the amœbæ and infusoria, where no special organs are manifest and no part therefore has needs differing from any other, there is found no circulatory system—no heart or propelling body or any blood-vessels. Its life depends upon diffusion throughout its parenchyma of substances brought from without and of those which must be excreted. It is only as special organs show themselves and the liquids take determined directions toward one or another of them, that blood-vessels are seen to commence; these at the same time become the receptacles of products absorbed for the purposes of nutrition and the distributors of these same materials to the various tissues of the organism.

It is, therefore, from complex organisms that the idea of a perfect *circulation* is gained, with its admirable mechanism for incessant movement whereby the fluid necessary for its growth, functions, and individual life is forced to every part. Viewed as a whole, the vascular system of the higher animals forms a system of branching vessels or canals, closed in all parts, and not showing at any point in their course the least perceptible orifice of communication with the external world. Consequently, the fluids which have to penetrate into the closed channels of circulation, as well as those which have to emerge from them for the needs of secretion and nutrition, only do so by passage through the vascular walls; that is, through the finest filters imaginable.

At a variable point in this tubular apparatus there exists an organ of propulsion, the *heart*, which is seconded in its work by auxiliary means and forces which aim to give a determined and constant direction to the movement of the circulatory fluid.

And where there is a circulatory system there is present some means, composed—in the great majority of cases—of muscle, for the impulsion of the circulatory fluid to every part of the organism. Whenever, in animal organisms, there is transformation of energy into motion or mechanical work, it may nearly always be attributed to muscle. So that in the higher forms of animals there exist one or more rhythmically contractile organs—for the most part muscular in nature—to which is attributed the task of maintaining a definite circulation.

Comparative.—Among insects and the lower orders of crustacea the heart, if such it may be called, is simply the contractile dorsal blood-vessel; among the higher crustacea, as the lobster, there exists dorsally a well-defined muscular sac. Among the invertebrates in general the blood passes from the arteries into irregular spaces, known as lacunæ, which are situated in the tissues and from which it finds its way back into the veins to terminate in the heart for the completion of its cycle. That interesting creature, the amphioxus, the lowest of the vertebrates, possesses a primitive, lacunar vascular system. Its contractile dorsal vessel serves as its systemic heart; a ventral vessel serves as a respiratory heart, vessels proceeding from it to the gills. Fishes contain only a respiratory heart, which sends blood to the gills for aëration. It consists of a venous sinus, an auricle, and a ventricle. From the gills blood finds its way to the aorta, to be distributed throughout the tissues without any further impulsion. Among the amphibians, as the frog, there are found two auricles and a single ventricle. Reptiles possess two auricles with two ventricles, though the latter are but incompletely separated. Among birds and mammals there is a heart which serves a double purpose—it sends blood to the lungs for aëration, to the body in general to serve the needs of its various tissues. The passage of the blood to the lungs is accomplished by the right auricle and ventricle and is known as the *pulmonary system.* That going to the tissues of the body is propelled by the left auricle and ventricle to constitute the *systemic system.*

THE CIRCULATORY SYSTEM.

This system has for its distinctive function the propulsion of the blood to every part of the economy. It is a closed, vascular apparatus consisting of an impelling agency, or pump, with an outgoing and incoming system of vessels. The central pumping organ is the *heart,* from which proceed the vessels that carry the blood *from* the heart to the various organs and parts of the body—the *arteries*—and the vessels returning the impoverished blood to the right side of the heart—the veins. Connecting the smallest arterioles and the fine radicals of the beginning veins is a network of microscopical vessels, large enough in many places to admit of but a single row of corpuscles and whose walls are composed of a single layer of endothelial cells; these are the *capillaries.*

THE HEART.

The heart is a hollow, cone-shaped organ of muscle. It is situated in the cavity of the thorax, inclosed by a serous sac: the pericardium. It lies between the lungs, rests on the diaphragm, and is located more on the left than on the right side. It is placed obliquely; its broad end, or base, by attachments to the blood-vessels, is fixed to the front of the vertebral column. The base of the heart extends from the fourth to the eighth dorsal vertebra. The apex is inclined downward, forward, and to the left, where it terminates just behind the interval between the fifth and sixth ribs, ¾ inch to the inner side of and 1½ inches below the nipple. The heart is 5 inches in length; in breadth, 3½ inches; and in thickness, 2½ inches.

The heart is brown in color, and on its surface has a longitudinal and a transverse groove, which shows a division of the organ in four parts: the two auricles and two ventricles. The heart increases in all dimensions up to a late period in life, thus augmenting its weight. The auricles are cavities having thin walls. The base of the heart is formed by the auricles. A partition separates them and they are connected with the great veins,—the cavæ and pulmonary veins,—by which they receive blood coming from every portion of the system. The aperture of communication between the auricles and ventricles is the auriculo-ventricular opening, which permits the blood to leave the auricle to enter the ventricle, but valves prevent it from running back into the auricle. The thick-walled parts of the heart are the ventricles, which become thicker in the direction of the apex. Like the auricles, they are separated by a partition and connected with the large arteries,—the pulmonary artery and aorta,—by which they send blood to the entire system. Both ventricles have valves called aortic and pulmonary, which prevent the reflow of the blood from the arteries into the ventricles.

The right auricle consists of an oblong part, the sinus. The walls of the right auricle are thin and translucent, but are thickened by means of isolated columns of muscle called the pectinate muscles. These pectinate muscles make the interior of the heart present an uneven, ridge-like appearance. On the partition between the auricles there is a shallow, oval fossa, with a border, which is the position of the foramen ovale, by which the two auricles communicated during intra-uterine life. The openings of small veins, the foramina Thebesii, can be seen at various parts of the inner surface of the right auricle.

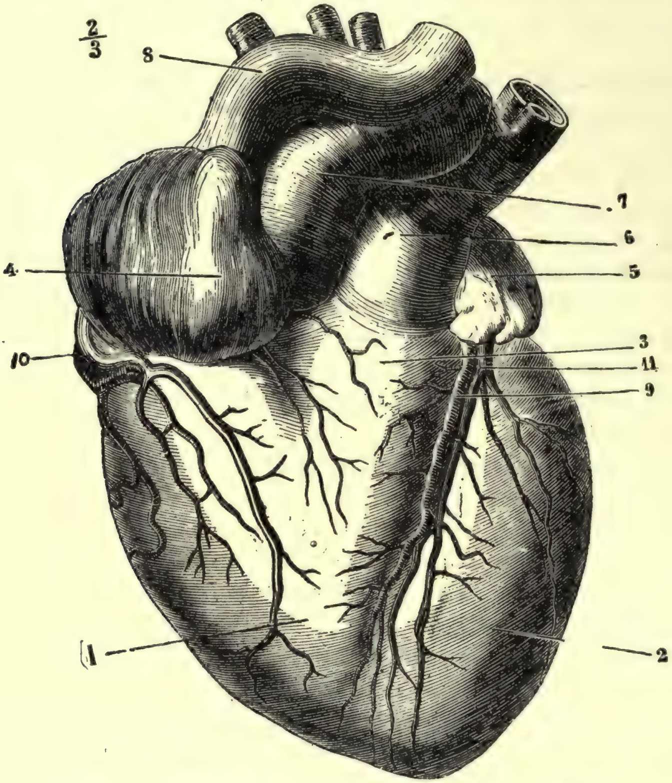


Fig. 62.—Anterior Surface of the Heart. (Bourgery.)

1, Right ventricle. 2, Left ventricle. 4, Right auricle. 5, Left auricle. 6, Pulmonary artery 7, Aorta. 8, Vena cava superior. 9, Anterior coronary artery. 10, Posterior coronary artery. 11, Coronary vein.

The auriculo-ventricular orifice of the right side of the heart is a large oval aperture. It is about an inch in diameter. It is guarded by the tricuspid valve, or right auriculo-ventricular valve.

The left auricle has thick walls, and the walls are not so translucent as those of the right auricle. It has a smooth interior surface, except with the auricular appendage, where pectinate muscles are present. It has four openings, which are the pulmonary veins, two in the right and two in the left side of the auricle. At the lower anterior part of the cavity is the left auriculo-ventricular orifice. The right ventricle is in the shape of a pyramid with the base upward and backward. It extends from the right auricle to near the apex of the heart, and occupies more of the front surface of the heart than the left ventricle. The walls of the right ventricle are only one-third the thickness of those of the left. The septum ventriculorum bulges into the right ventricle. There are

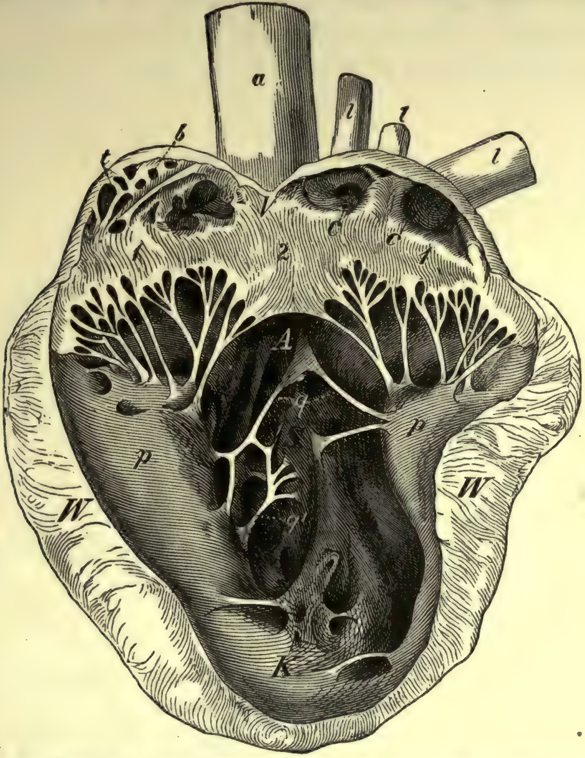


Fig. 63.—Heart of the Cow, with Left Auricle and Ventricle Laid Open. (Müller.)

a, Root of the aorta. *b*, Spaces in the wall of the auricle. *c*, *c*, Orifices of the pulmonary veins. *l*, *l*, Pulmonary veins. *p*, *p*, Papillary muscles. *q*, *q*, Columnæ carneæ. *A*, Orifice of the aorta. *K*, Left ventricle. *S*, Septum. *V*, Left auricle. *W*, Lateral wall of left ventricle. 1, 1, 2, Leaflets of mitral valve.

numerous projecting ridges in the right ventricle which are muscles called the columnæ carneæ. Some of them are named, from their shape, the papillary muscles, which project from the interior surface of the ventricle and end in narrow tendinous cords called the chordæ tendineæ.

The right auriculo-ventricular orifice opens into the ventricle at its lower back part. From its edges projects a broad, membranous fold divided into three parts and hence called the tricuspid, whose free borders are attached by the chordæ tendineæ to the papillary muscles and to other points on the interior surface of the ventricle. When the valve is open the three parts lie against the interior surface of the ventricle. The duplicature of the endocardium with included fibrous tissue makes up the tricuspid valve and the chordæ tendineæ. The pulmonary artery springs from the base of the right ventricle. Its opening is provided with three semilunar valves. These valves are three crescentric doublings of the endocardium with fibrous tissue and are arranged in a circle. Their convex border is attached around the edge of the orifice of

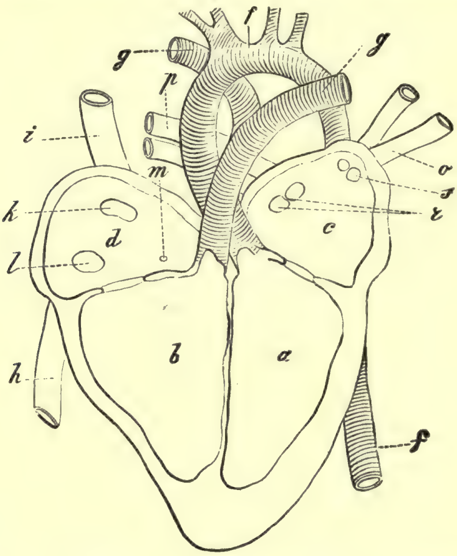


Fig. 64.—Diagram of Mammalian Heart. (Beclard.)

a, Left ventricle. *b*, Right ventricle. *c*, Left auricle. *d*, Right auricle. *f*, Aorta. *g*, *g*, Pulmonary arteries. *h*, Inferior vena cava. *i*, Superior vena cava. *k*, Orifice of superior vena cava. *l*, Orifice of inferior vena cava. *m*, Orifice of the coronary vein. *o*, Left pulmonary vein. *p*, Right pulmonary vein. *r*, Orifice of the right pulmonary vein. *s*, Orifice of the left pulmonary vein.

the artery. Behind each valve the artery is dilated into a shallow pouch, called the sinus of Valsalva, which prevents the valve, when open, from adhering to the side of the artery and permits the reflow of blood to readily press the valve down to close the opening. At the middle of the free border of the valve there is a thickening of fibrous tissue, making the corpora Arantii. The left ventricle is three times the thickness of the right, and its apex forms the apex of the heart. It is longer and forms more of the posterior surface of the heart than the right ventricle. Like the right ventricle, it has columnæ carneæ, papillary muscles, and chordæ tendineæ.

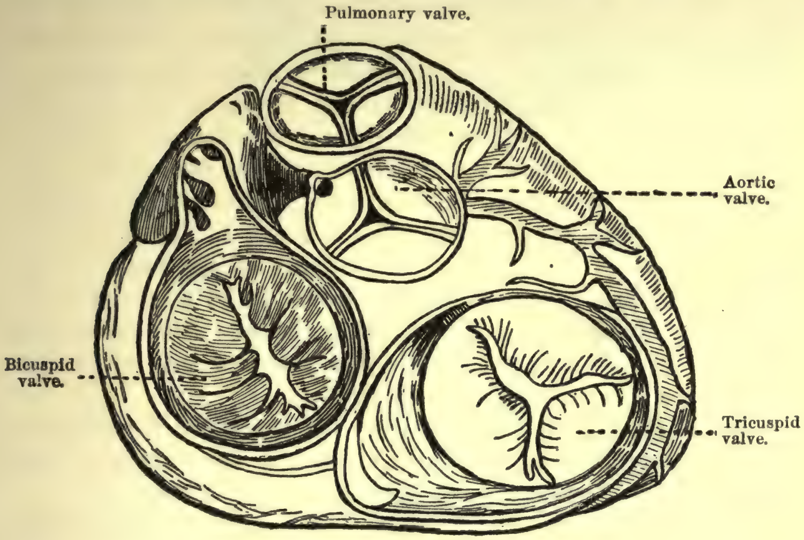


Fig. 65.—Valves of Heart.

The left auriculo-ventricular valve is provided with a pair of membranous folds forming the mitral valve, or bicuspid valve. It is larger in size and thicker than the right auriculo-ventricular valve. These mitral segments have the chordæ tendineæ attached.

The left ventricle has an opening which is the origin of the great blood-vessel, the aorta. It is provided with semi-lunar or sigmoid valves, of the same character as those of the pulmonary artery.

Structure of the Heart.

The lining membrane of the heart is called the endocardium. All the valves of the heart are made up by its inclosing fibrous tissue. The endocardium is formed of epithelium and fibro-elastic tissue. The rings to which the valves are attached are also made of endocardium and fibro-elastic tissue.

Muscular Structure of the Heart.

The muscular fibers of the auricles consist of two layers running in different directions. The external fibers are common to both auricles, whilst some run into the interauricular septum. The internal fibers are not common to both auricles, but are confined to each auricle. The fibers of the internal layer are attached to their respective auriculo-ventricular rings. The external fibers run in a transverse direction; the internal fibers cross the direction of the former. There are other muscular fibers, arranged concentrically around the origin of the great veins and auricular appendages.

In the ventricles there are several layers of muscles. The outer layer runs from the base, where they are attached to the fibro-cartilaginous rings around the orifices toward the apex of the heart, where they run by a sharp twist into the interior of the left ventricle to the papillary muscles. This twisting of the fibers gives rise to the whorl of the fibers at the apex of the heart. Other fibers run obliquely upward in the septum to be attached to the fibro-cartilaginous ring, from which they started. Still other fibers pass in a horizontal direction into the posterior wall of the left ventricle and take a ring-like course in it.

W. G. MacCallum found beneath the superficial fibers thicker fibers which form three flat bands running in the form of a scroll from one ventricle through the septum into the other.

The right ventricle in the arrangement of its muscular fibers may be regarded as an appendage of the left.

Histology.—The fibers of the heart are striated. Unlike the voluntary muscle, they branch and have their ends united to each other so as to form a network. The open space in the network is filled with connective tissue and lymphatics. The muscle-cells are quadrangular in shape, with clear oval nuclei. There is no sarcolemma in heart-muscle. The muscles of the heart anastomose and divide. As to lymphatics, the heart is very liberally supplied with them. The nerves are nonmedullated near their ends. The muscular mass of the heart is called the myocardium.

Gibson[1], in a histological study of the auricular muscles of the heart, found three kinds of tissue: (1) those related to smooth muscular fiber found chiefly in the vicinity of the foramen ovale and in the valve of Vieussens; (2) those having a syncytial arrangement found for the most part in relation to the superior vena cava and the parts related thereto; (3) those of a reticular structure of the sino-auricular node (Keith and Flack), and the tissue encircling the greater part of the superior circumference of the superior-vena cava and the valve of Vieussens. Gibson supposes the syncytial fibers may originate the heart-beat.

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[1] British Medical Journal, January 16, 1909.

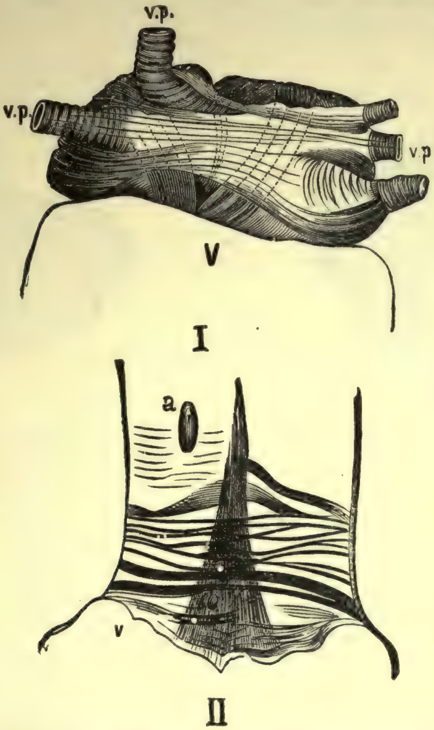

Fig. 66.—Course of Muscular Fibers of Heart. (LANDOIS.)

I. Course of the muscular fibers on the left auricle, with the outer transverse and inner longitudinal fibers, the circular fibers on the pulmonary veins (*v. p.*). *V*, The left ventricle. (JOHN REID.)

II. Arrangement of the striped muscular fibers on the superior vena cava. *a*, Opening of the vena azygos. *V*, Auricle. (ELISCHER.)

Pericardium.—This is a fibro-serous sac inclosing the heart, and consists of two leaves, or layers. The internal serous, or visceral, layer closely invests the heart and the commencement of the great blood-vessels. It is an inextensible membrane.

The external fibrous, or parietal, layer is a strong, inelastic membrane which embraces the origin of the great blood-vessels at the base of the heart.

These two layers unite to make a close sac. Between the parietal and visceral layers is the pericardial liquor, which permits the two layers to slide on each other without friction. The elastic fibers in the parietal layer permit of its following very closely the changing form of the heart.

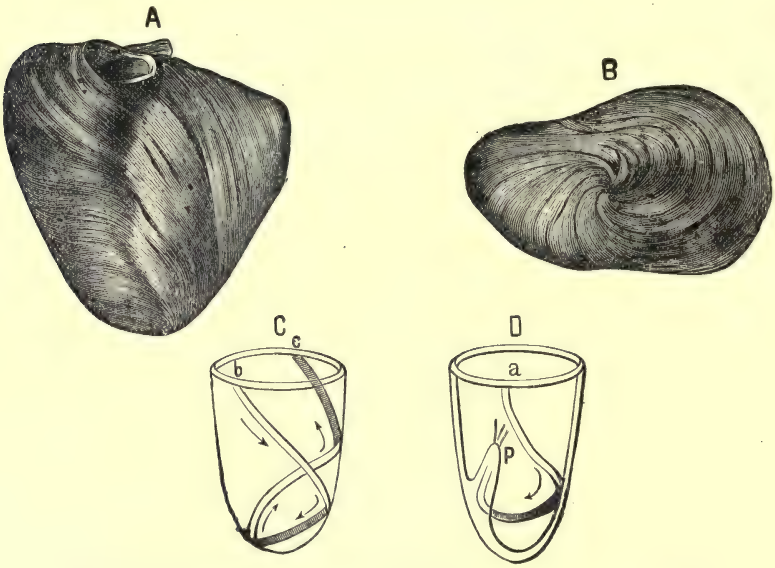

Fig. 67.—Course of the Ventricular Muscular Fibers. (Landois.)

A, On the anterior surface. *B*, View of the apex with the vortex. *C*, Course of the fibers within the ventricular wall. *D*, Fibers passing into a papillary muscle, *P*.

The Auricles.—In examining each half of the heart it is easy to recognize that the auricle, on account of the thinness and the weakness of its muscular walls, can scarcely be the important part of that organ. In laying bare the heart of an animal while artificial respiration is maintained, it is seen that the action of the auricle is very weak as compared with that of the ventricle. A manometer introduced into the auricular cavity at the moment when it contracts marks a pressure that is five or six times less than that obtained in the corresponding ventricular cavity under the same conditions.

The pressure in the auricles is lowest at the period of diastole, and since, then, the pressure in the veins is greater than the pressure in the auricles, there is a flow of blood into the auricles, which gradually becomes less. When the ventricles dilate, another fall in the auricular pressure takes place and another rush of blood follows. The opening of the great veins is contracted, and this act, preceding the contraction of the auricle, drives the blood from the veins into the auricles. When the auricles contract, the blood cannot flow back into the veins to any great extent.

The Ventricles.—The ventricles represent the parts that are really active in the cardiac circulation. The strength of the contractions proper to the two ventricles reveals itself in the thickness of the muscular walls, the fibers of which are inserted into fibrous rings. These latter are the veritable skeleton of the heart. Manometric observation presents us with proof of the force of the ventricular contractions.

GENERAL COURSE OF THE CIRCULATION.

Since the main points of the anatomy of the heart have been touched upon, it might be well at this stage roughly to consider the circuit of the blood through it and its vessels. The vascular system is a closed apparatus consisting of a central pump with its vessels leading to every part and organ of the economy. *All* vessels leading *away* from the heart are *arteries;* those leading *toward* it are *veins.*

The entire circuit of the blood is divided into two principal portions, which are distinctly separated from one another both anatomically and functionally. The one conveys the blood to and from the lungs during the process of aëration; so that to it has been affixed the term *pulmonary circulation.* The other has for its function the distribution of the blood to all parts and organs of the economy in general, thereby receiving the name *systemic circulation.*

Beginning with the left ventricle, the blood is conveyed to the aorta, from which branches are distributed to every part of the body, through the capillaries to the veins, to be eventually returned as dark, impure blood to the right auricle. This, the greater circuit, has been termed the *systemic circulation.* During the course of this circulation it has been found that the blood from the capillaries of some of the abdominal viscera is gathered together into a single vessel, the *portal vein,* which again subdivides to form a capillary plexus in the liver. This *accessory* circulation is commonly designated as the *portal circulation.*

From the right auricle the blood flows into the right ventricle, from which it is expelled through the pulmonary artery to the lungs,

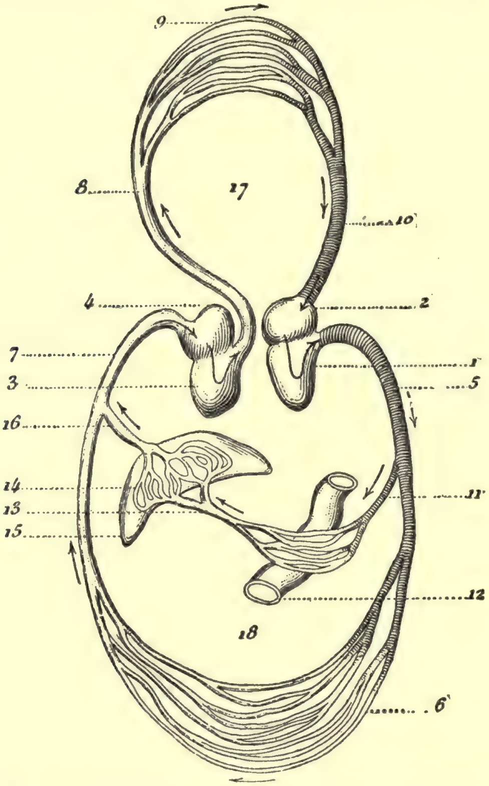

Fig. 68.—Diagram of the Circulation. (Duval.)

1, Left ventricle. 2, Left auricle. 3, Right ventricle. 4, Right auricle. 5, Aorta. 6, Systemic capillaries. 7, Inferior vena cava. 8, Pulmonary artery. 9, Pulmonary capillaries. 10, Pulmonary vein. 11, Gastric and intestinal vessels. 12, Intestine. 13, Portal vein. 14, Portal vein, forming second capillary system in the liver. 15, Liver. 16, Hepatic vein. 17, Pulmonary, or lesser, circulation. 18, Systemic, or greater, circulation.

to be returned to the left auricle as bright-red, pure blood. This change in color is due to the presence of oxygen in the hæmoglobin gained during the process of aëration. This shorter circuit is known as the *lesser*, or *pulmonary,* circulation.

Difference of pressure between the blood of the aorta and pulmonary artery, on the one hand, and that in the venæ cavæ and pulmonary veins, on the other hand, is responsible for the *flow* of blood. Its direction is always in the line of least resistance. The greater the difference of pressure, the greater is the velocity of the blood-stream; the reduction of this difference to *nil*, as in death, results in no movement.

MOVEMENTS OF THE HEART.

The heart movements consist of alternate contractions and relaxations, which follow each other with a certain rhythm. Systole is the name for contraction; diastole is the term for relaxation.

The two auricles contract and relax synchronously, and these movements are followed by a simultaneous contraction and relaxation of the ventricles. There is a systole and diastole of auricles and a systole and diastole of ventricles. At last there is a very short period in which the heart is in diastole.

The auricular contraction is less sudden than the ventricular. The contraction of the auricle lasts a very short time, while the time of ventricular contraction is considerable, and the relaxation of the ventricle is slow.

The ventricular diastole is nearly twice as long as the ventricular systole. The auricles have a uniform, wavelike movement; the ventricles have a spasmodic action in their movement. If now the venæ cavæ and pulmonary veins are delivering blood into the two auricles, then at this time the diastole of the auricles is gradually approaching completeness. The swelling of the auricles is due, in part, to the pressure in the veins being greater than in the cavity of the auricles and in part to the inspiratory movement of the thorax sucking the blood from the veins external to the thorax to the interior of the veins of the chest. During this period the ventricles are filling with blood, for both the tricuspid and mitral valves are open. As the cavity of the auricles is smaller than that of the ventricles, the auricles are filled sooner, and consequently contract before the ventricles, the veins offering a resistance to the backward movement of the blood by a narrowing of their opening. The systole of the auricle forces the blood chiefly in the line of least resistance with the ventricle, which is not yet completely filled and is undergoing diastole. Whilst the blood is passing from the auricles into the ventricles the auriculo-ventricular valves are floated gradually into a horizontal position. The blood by the systole of the auricles has filled the ventricles, already filled in part during the diastole of the auricle. Now the ventricles contract, the mitral and tricuspid valves are tightly pressed together, and regurgitation of blood into the auricles is prevented. Now, as the blood cannot go back into the auricles, it must by the muscular force of the ventricles rush into the pulmonary artery and aorta, respectively. The onset of the blood forces open the semilunar valves of the pulmonary artery and aorta, and exerts a pressure in these arteries partially filled with blood before the new rush of blood sets in. Their walls are necessarily considerably distended. Then the ventricles dilate and at the same time the mitral and tricuspid valves open, and the semilunar valves close from the recoil of blood against them. From the time the systole of the ventricles ends to the full distension of the auricles, all the chambers of the heart are in diastole and are being filled with blood. This is the resting of the heart, and is called the pause.

In the general diastole of the heart, the heart fills itself, the blood passes from the auricles into the ventricles under the influence of the venous blood-pressure. There are three factors which help in the filling of the heart. First, diastolic aspiration of the heart produced by the rapid relaxation of its elastic walls. The second cause is the auricular aspiration produced by the ventricular systole. At the time corresponding exactly to the period of evacuation of the heart by a systole a sudden depression ensues in the auricle, a venous aspiration into the auricle, because the ventricles in contracting shorten, but the apex of the heart is not displaced, for the base of the ventricles is pulled towards the apex of the heart; the auriculo-ventricular valves being closed at that time, they are carried along with the ventricle. The floor of the cavities of the auricle is perceptibly lowered and the cavity of the auricle is enlarged. This aspiration of the heart is especially noticeable in the vena cava, but a less marked aspiration is seen in the pulmonary veins. The third cause in the filling of the heart in a state of general diastole of the heart is the thoracic aspiration.

PULMONARY CIRCULATION.

It must be remembered that the right and left auricles fill in the same time; whilst the blood is running into the right auricle from the vena cava, the blood is flowing from the pulmonary veins into the left auricle in the same quantity and with the same rapidity.

The quantity of blood which the right ventricle sends into the lungs must be the same in quantity as that ejected by the left ventricle. If the same quantity of blood is not ejected by the two ventricles at each contraction the blood accumulates somewhere in the vascular system.

Whilst the blood-pressure in the lungs is very low, the variations in pressure are very small, not more than 10 to 15 millimeters in physiological conditions. The variations of blood-pressure in the systemic circulation are much greater. Hence the work of the right ventricle does not vary much, whilst that of the left ventricle must vary considerably; hence it is more easily fatigued than the right ventricle.

If the left ventricle is not able to eject all its blood on account of the resistance in the periphery, then the blood cannot flow readily from the right heart. As a rule, this effect on the right heart by an incomplete evacuation of the left ventricle is counteracted by the great capacity of the pulmonary vessels, which accommodate this backing up of blood and permits it to absorb the greatest quantity of oxygen. The resistance to the flow of blood in the pulmonary circulation is very small, and the blood makes its circuit in 6 to 7 seconds.

GENERAL SHAPE OF THE HEART.

During ventricular systole the heart undergoes a torsion around its vertical axis; a twisting from left to right anteriorly by which the left ventricle gets in front. The ventricles during their diastole have a general conical form which during their systole becomes globe-like. This change of form also alters the diameter of the heart. The vertical diameter is lessened by the contraction of the cardiac muscle. The transverse diameter from right to left is diminished by the change to a sphere during the systole of the ventricles. There is an increase in the antero-posterior diameter from the spherical form of the ventricle. The heart is in close contact with the walls of the chest by this globular form during the systole.

CHANGE IN VOLUME.

In plethysmographic studies of the heart it is found that there is a diminution of its volume during ventricular systole.

CHANGE IN CONSISTENCY.

The hardening of the heart during systole is of great importance in the explanation of the cardiac impulse. If you simply touch the heart of a living animal you obtain considerable information as to the energy of the cardiac contraction.

CARDIAC REVOLUTION OR CYCLE.

A cardiac revolution or cardiac cycle shows that the heart-muscle has alternate contractions and relaxations. The cycle means that the heart at any particular time experiences certain changes until it once more takes on the same condition that it had at the time when the observation began.

The right and left auricles contract at the same time forming the auricular systole; this is succeeded by contraction at the same time of the right and left ventricles; then the whole heart is in a state of rest, a general relaxation or diastole. Then the revolution again begins.

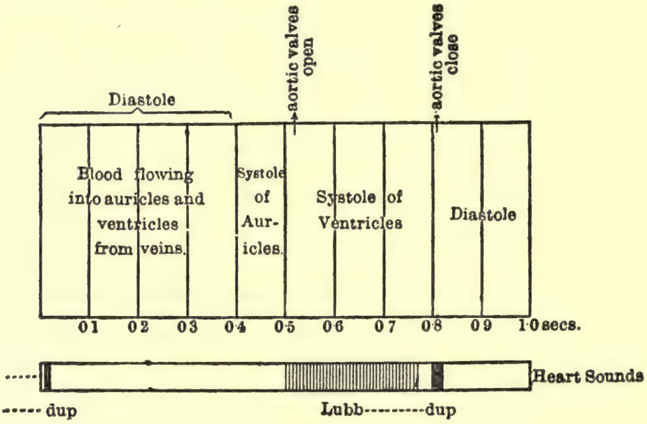
aortic valves open
aortic valves close
Diastole
Blood flowing into auricles and ventricles from veins.
Systole of Auricles.
Systole of Ventricles
Diastole
01
02
03
0·4
0·5
0·6
0·7
0·8
0·9
1·0 secs.
Heart Sounds
----- dup
Lubb--------dup

Fig. 69.—A Cardiac Cycle. (Starling.)

The cardiac revolution may be divided as follows: (1) the *first sound;* (2) the *first,* or short, *silence;* (3) the *second sound;* and, (4) the *second,* or long, *silence.*

If the cardiac revolution be divided into tenths, then the first sound will be $^{4}/_{10}$; the first silence, $^{1}/_{10}$; the second sound, $^{2}/_{10}$; and the long silence, $^{3}/_{10}$.

The time of the various acts of the total cardiac movement in man are, according to Gibson, as follows:—

Auricular systole	0.112 second.
Ventricular systole	0.368 second.
Ventricular diastole	0.578 second.
Cardiac cycle	1.058 seconds.

Auricular diastole is about 0.64 seconds, hence its time is longer than that of a systole of the auricle. It has been found by Einthoven and Geluk by the most accurate measurements in fifteen human hearts that ventricular systole may take 0.312 to 0.346 seconds, whilst diastole may be 0.385 to 0.518 seconds. If the frequency of the heart is greater the time taken by each revolution is shorter, but the diminution is mainly in the diastole, when the heart rests and recovers its systolic power. Whatever may be the rate of the heart-beat, the auricular and ventricular systoles do not vary much, but in a rapidly acting heart the pause is short, in a slow beating heart it is long.

The diastole of all the four cavities of the heart is longer than their systole, and it is about a half second from the end of the contraction of the ventricles to the commencement of the contraction of the auricles, a period of cardiac rest. It has been estimated that the human heart works about nine hours and rests about fifteen hours in a day.

The rhythmical succession of these acts constitutes the cardiac revolution. By their function the vital fluid—the blood—is kept in constant circulation within the body so that every portion of the economy receives its proper nourishment. The processes of metabolism are balanced, the various organs and glands of the body perform their needed functions, and the whole animal lives and thrives.

The events in a cardiac revolution can be tabulated as follows:—

1st period.	2d period.	3rd period.
Auricular systole. Accomplishment of ventricular diastole.	Ventricular systole. Closure of mitral and tricuspid valves. Opening of semilunar valves. The blood is thrown into the aortic and pulmonary arteries. Cardiac impulse. Diastole of the arteries and the pulse. Auricular diastole.	General diastole of the heart. Closure of semilunar valves. The blood pours into the auricles, and a little into the ventricles.

To physiologists, the first period in the movement of the heart coincides with contraction of the auricles. The clinicians take the first period at the moment of ventricular systole.

CARDIAC IMPULSE.

The cardiac revolution is manifested by two signs, the cardiac impulse and the sounds of the heart. There are two things to be noted in the production of the cardiac impulse. The first thing is the intimate contact of the heart with the wall of the thorax during the increase of the antero-posterior diameter by the cardiac systole, and the second is the simultaneous and sudden hardening of the ventricles. It suffices simply to press the finger deeply into the intercostal space to perceive the hardening of the ventricle at the moment of its production.

This area is located in the fifth left intercostal space between the mammary and midsternal lines. The center of this area is described as being two inches below the nipple and one inch to its sternal side.

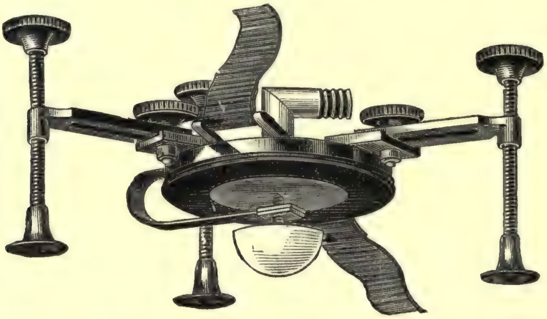

Fig. 70.—Sanderson Cardiograph.

The cause of the impulse of the heart is not the apex but the change in form and consistency of the ventricles, when these pass from the diastole to the systole and in the instantaneous transformation. It is the sudden hardening of the ventricle.

The impulse takes place at the same time as the systole of the ventricle, and is caused by the ventricle, which is pressed very firmly against the chest. At the time of the contraction of the ventricle the outline of the heart changes; instead of being an oblique cone having an elliptical base, as at rest, it becomes a regular cone with a regular base.

For giving more accurate accounts of the heart's movements recourse is had to the instruments called *cardiographs.*

Cardiographs.—These are instruments which give graphic records of the heart's movements. They register at the same time the movements of the auricles, ventricles, and the beating of the heart against the walls of the chest. There are, to-day, numerous cardiographs, all of them, however, being only modifications of Marey's tambours.

Sanderson's instrument consists of a hollow disc, the rim and back of which are of brass, while the front is of thin rubber. On its back is a flat steel spring bent at right angles, and its unattached end is provided with an ivory button which is directly over the center of the rubber membrane. The ivory button is applied over the point where the apex-beat is most plainly felt. During the application of the apparatus the ivory button is kept continually in motion by the surface pulsations. Each movement of the button sets the rubber membrane in motion, and, as the drum is airtight and in communication with a second drum with a recording lever, the diminution of air in the first causes an increase in the content of air in the second, and an elevation of its recording lever on a smoked drum. Each systole of the ventricle causes a sudden rise of the lever, and the end of the systole is noted by a marked gradual descent of it.

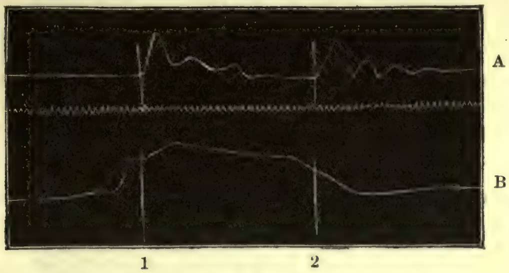

Fig. 71.—Cardiogram (*B*) with Simultaneous Record of Heart-sounds (*A*). (Hürthle, Starling.)

1, Position of first sound. 2, Position of second heart-sound. The first heart-sound corresponding to the systole of the ventricle begins at the notch in the cardiogram near the top of the ascent; hence the ascent of curve preceding this notch is due to auricular systole forcing blood into the ventricle, and the ventricular systole is indicated by the notch.

The cardiogram is read from left to right, and normally shows a small elevation, corresponding to auricular systole, immediately succeeded by a very abrupt rise which marks ventricular systole. This is held for 0.3 of a second and presents small vibrations, which are attributed to the closure of the semilunar valves. The very abrupt, downward stroke marks the pause, or diastole.

Clinically, changes in the cardiac impulse are best ascertained by using any of the graphic instruments and then studying the curves obtained. From such study the observer is able to get very definite knowledge as to the nature of the cardiac lesion, its severity, etc. The various stenoses, insufficiencies, hypertrophies, and dilatations may by this means be diagnosed with considerable accuracy.

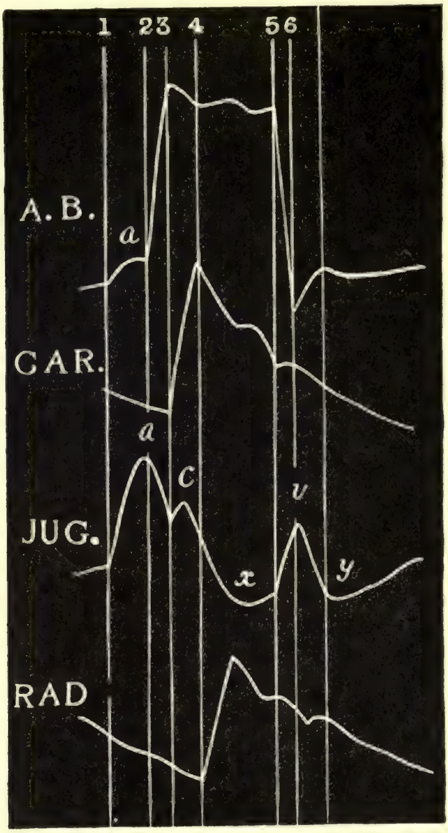

Fig. 71a.—Diagram Showing the Relations of the Cardiogram (*AB*), the Pulse in the Carotid (*CAR*), the Jugular Pulse (*JUG*), and the Radial Pulse (*RAD*) to each other.

The perpendicular lines represent the time of the following events: 1, The beginning of auricular systole. 2, The beginning of ventricular systole. 3, The appearance of the pulse in the carotid. 4, The appearance of the pulse in the radial. 5, The closure of the semilunar valves. 6, The opening of the tricuspid valves. (Hay.)

Endocardiac Pressure.—The ordinary mercurial manometer, by which the heart's work can be estimated, is unsuitable for determining its ventricular pressure. The objections are the relatively great amount of work required to produce a given displacement of the mercury; that it is not susceptible and sensitive to quickly follow differences of pressure; and when once displaced, the mercury possesses enough oscillations of its own which confuse oscillations of blood-pressure. However, when this instrument by the introduction of a properly placed valve is converted into a "maximum and minimum manometer," the actual blood-pressure may be more readily determined.

The dog has been very extensively used for the application of this instrument, as a consequence of which the appended figures are given:—

	SYSTOLE. MAXIMUM PRESSURE.	DIASTOLE. MINIMUM PRESSURE.
Left ventricle	140 millimeters.	—30 to 40 millimeters.
Right ventricle	60 "	— 15 "
Right auricle	20 "	— 7 to 8 "

By negative pressure is meant that the mercury in the instrument has been sucked toward the heart. The negative pressure, as is seen, occurs only during the diastole of the heart. Moens is of the opinion that this negative pressure within the ventricle happens shortly before the systole has reached its height. During negative pressure the blood from the veins is sucked into the heart.

For determination of the duration of the cardiac events, as well as the blood-pressure—that is, to have tracings of the curves for each cavity, to know the time-relations for comparisons, as well as the curves of the great arteries and veins—requires an instrument of some complexity. Only within recent years have these been invented, by Chauveau and Marey, whereby elastic manometers counterbalance the blood-pressure instead of a column of liquid. Many of the instruments employed give their tracings from movements transmitted to them from cardiac sounds through a tube to the recording apparatus. The sounds were usually appropriately curved cannulæ, to one end of which were attached flexible rubber bags, or ampullæ. Two were introduced through the jugular vein into the right auricule and ventricle, a third into an intercostal space in front of the heart. These were put into communication with three tambours with their needles, by which were recorded the endocardiac pressure with the duration of the auricular and ventricular contractions.

By these levers it was shown without doubt that the apex-beat is due to the systole of the ventricle, as the two were synchronous.

Pressure Curve in the Ventricle.—Experiments on ventricular pressure have been made with Fick's elastic manometer and the differential manometer of Hürthle. Dr. Porter, of Harvard, has made a study of this subject with the instrument of Hürthle, and I shall follow him in the description of the curves obtained.

Porter (Fig. 72), with his predecessors, has shown that the systolic muscular contractions begin quite suddenly, producing a swift rise of pressure. The diastolic fall of pressure is nearly as sudden as the rise. In the fall of diastolic pressure, the pen often reaches below the pressure of the atmosphere. Between the systolic rise and the diastolic fall it is found that the systolic pressure causes its curve to bend alternately downward and upward. Between these two points the general direction of the curve approaches the horizontal, and thus may be denominated the "systolic plateau." The curve of intraventricular pressure rarely gives any clear indication of the beginning or end of auricular systole. The ventricular pressure curve does not give any clear indication

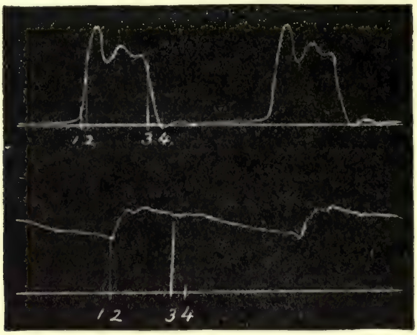

Fig. 72.—Magnified curve of the course of pressure within the left ventricle and the aorta of the dog, the chest being open; to be read from left to right. Recorded simultaneously by two elastic manometers with transmission by liquid. (Porter.)

In both curves the ordinates having the same numbers have the following meaning: 1, The instant preceding the closing of the mitral valve. 2, The opening of the semilunar valve. 3, The beginning of the "dicrotic wave," regarded as marking the instant of closure of the semilunar valve. 4, The instant preceding the opening of the mitral valve.

of the moment of closing or opening of either auriculo-ventricular or semilunar valves. These instances can, however, be marked upon it after they have been obtained in an indirect manner.

In Fig. 72 the ordinate 1 indicates the closing, and ordinate 4 the opening of the mitral valve; ordinate 2 indicates the opening, and ordinate 3 the closing of the aortic valve. In the arterial curve, 2 marks the beginning of the systolic rise and 3 the beginning of the dicrotic wave, which corresponds closely to the closure of the aortic valve.

During the period when the bicuspid valve is open, the pressure is lower in the ventricle than in the artery, the aortic valve is shut, and blood is entering the ventricle, this being the "period of the reception of blood." During the greater part of the period when the bicuspid valve is shut, the aortic valve is open, the pressure is higher in the ventricle than in the artery, the ejection of blood is taking place, this being the "period of ejection," which lies between the ordinates 2 and 3 (Fig. 72).

There are two brief periods, during each of which both valves are shut and the ventricle is a closed cavity; one immediately precedes the period of ejection, the other immediately follows it. The explanation of these periods is that it takes a brief time for the cardiac muscle, contracting upon the blood in the closed ventricle, to raise the pressure to the high point required to overcome the opposing pressure within the artery and to open the aortic valve. Hence the ventricular cycle is composed of four periods: the first, the period of complete closure with strongly rising pressure; the second, the period of ejection, relatively long; the third, a period of complete closure, with swiftly falling pressure; the fourth is the period when the pressure is low and blood is entering the ventricle.

Persistence of the Heart Movement.—The heart may continue to beat for some time after its removal from the body. This is particularly noticeable in cold-blooded animals like the turtle, whose heart movements have been known to continue, even for days.

When the heart dies the ventricles stop first, but the right auricle is the last to be arrested; hence it is called the "*ultimum moriens.*"

W. Koch observed the dying heart in the human fœtus and the last part to cease beating was not the root of the superior vena cava but in the wall of the coronary vein of the heart which he thinks corresponds embryologically to the sinus venosus.

SOUNDS OF THE HEART.

When the ear is placed over the cardiac region, or to a stethoscope applied to the precordial area, *two* characteristic *sounds* are heard. The two sounds are known as the *first* sound and *second* sound, and are emitted during every cardiac revolution. Though the sounds occur in quick succession, yet they are each separated by silences.

The *first sound* is the stronger of the two. In nature it is dull. It coincides with the shock of the heart. The first sound is followed by the first, or *short, silence.*

The *second sound* is shorter in duration and clearer in character than the first. It comes an instant afterward, at the moment when the whole heart is in relaxation. In *pitch,* the second sound is from one-fourth to one-third higher than that of the first sound.

Following the second sound of the heart there occurs the *second,* or *long, silence.* In reality the pause occupies but a fraction of a second, yet it is said to be "long" as compared with the first silence.

It must be borne in mind by the student that there occur in reality *four sounds* during each cardiac cycle. However, the first two normally occur in unison, as do the second two, so that but two sounds are heard by the examiner.

From their difference in *pitch* the two heart-sounds may be expressed graphically upon the musical staff. To the ear they simulate the sounds which are produced in pronouncing the words, "lubb," "dup," the former corresponding to the first heart-sound, the latter to the second.

If the two sounds be listened to at some distance from the heart, the first may nearly always be distinguished from the second by comparing the intervals between them. The time elapsing between the first and second sounds is generally much shorter than that which separates the second sound from the first in the succeeding revolution of the heart. But, in medical practice, too much importance must not be attached to these intervals, since their respective duration is extremely variable. In the absence of the impulse it is better to depend upon the differences of *pitch.*

Causes of the Sounds.—The nature and causes of the cardiac sounds are best studied in a large mammal whose heart-action is comparatively slow. For this purpose the horse is used. Its pulse averages but forty. The animal is properly prepared by anæsthetizing, curarizing, and exposing the viscus to view by placing a window in the thorax. With stethoscope and by observation and palpation, the experimenter is ready to determine, among the complex actions which make up a cardiac cycle, the one which gives rise to each of the two sounds.

SECOND SOUND.—The *cause* of the second sound is the sudden closure of the *sigmoid* (semilunar) *valves* of the aorta and pulmonary artery during relaxation of the ventricle. The sudden closing of the valves is produced during the effort of the arterial blood to escape backward from the elastic reaction of the aorta and pulmonary artery.

Proofs abound in support of this theory. If the valvular movements be hindered in one of the above-mentioned arteries by placing a clamp close to its base, immediately the second sound is suppressed at that point. If the valvular action of both vessels be suppressed, the second sound may be completely extinguished.

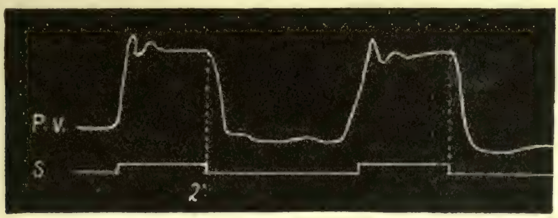

Fig. 73.—The Action of the Semilunar Valves. (CHAUVEAU.)

***Pv*, Tracing of the variations of pressure in the left ventricle. 2, Means second sound. *S*, Tracing by the signal magnet showing the action of the valve which by its movements closes and opens an electric current to the signal magnet. The second sound (closure of the semilunar valves) corresponds to the moment when the ventricle relaxes, that is, at the beginning of the ventricular diastole.**

Again, should the apex of the heart be cut off and the ventricular blood be made to escape to the outside, no second sound occurs. In this experiment the sigmoid valves have neither been lifted up nor allowed to fall back and stretch themselves out with a sound.

Physically, one is able to account for the production of the second sound on the principle that it is produced by the clicking of the sigmoid valves. In fact, similar sounds are obtained by producing sudden tension of a membrane under the action of a column of liquid.

When the initial stump of an aorta, whose valves are still intact, is attached to a tube and the reflux of the liquid closes the valves, a clear, snappy click is produced.

When pathological conditions occur, the sound is altered, being accompanied by or even altogether replaced by a blowing sound, known as a "murmur."

THE CAUSE OF THE FIRST SOUND is more difficult to determine than is that of the second. The nature of this sound is more complex, several factors entering into its evolvement.

Since it is established that the first sound corresponds in point of time with ventricular systole, it is reasonable to connect it with one or several phenomena which take place in the heart at that moment. They are: The precordial shock, contraction of the ventricles, occlusion of the auriculo-ventricular valves, and opening of the sigmoid valves.

While the above phenomena are synchronous with the first sound, yet the majority of them are believed to have no action in producing the first sound. Thus, the sound is audible in a heart before which the chest-wall has been removed, so that precordial shock is not the source of the sound.

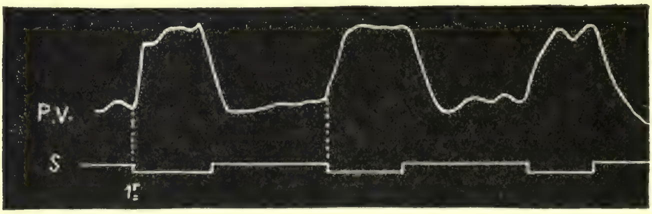

Fig. 74.—The Action of the Tricuspid Valve. (CHAUVEAU.)

Pv, Tracing of the variations of pressure in the right ventricle. 1, Means first sound. *S*, Tracing by the signal magnet, showing the action of the valve, which by its movements closes and opens an electric current to the signal magnet. The first sound (closure of the auriculo-ventricular valves) is simultaneous with the beginning of the ventricular systole and it produces during the first sound a rapid ascent of the curve of ventricular pressure.

That the opening of the sigmoid (semilunar) valves is not of consequence has long been refuted by experiment.

In the case of the second sound we just learned that the production of it was due to the closure of the sigmoid valves. In like manner the closure of the auriculo-ventricular valves is *in part* the cause of the first sound. Wintrich, by means of proper resonators, was able to analyze the first sound and so distinguish the clear, snappy valvular component of this so-called *solid sound.* The very fact that the sound is low and booming in nature demonstrates the fact that there must be some other component entering into its causation.

The tension and vibration of the chordæ tendineæ are factors in producing sound, but the nature of it is similar in every respect to that produced by valvular vibration.

Even though the auriculo-ventricular valves and their chordæ tendineæ be destroyed in an excised heart, yet will there be produced a feeble sound of rather low pitch. This sound is believed to be produced by the contraction of the muscular fibres of ventricular walls, and has been termed *"muscle-sound."*

Any muscle whatever, during its contraction, gives rise to a dull sound. It is evident then that, during contraction of the ventricle, this same phenomenon must occur and so contribute its part to the production of the first sound.

From new experiments it appears that the rôle of the muscular contraction is more important than it has generally been thought to be. For verification of this the following experiment seems to be decisive:—

The heart is exposed in a dog which has been poisoned with curare and in which artificial respiration has been maintained during two hours. The left ventricle is cut open in front and at the back with scissors along the intraventricular partition. The incisions are rapidly lengthened from the apex toward the base in such a manner as to turn completely outside all the ventricular wall. This portion is no longer held to the rest of the heart except by the auricle.

The suspended piece of ventricular wall, under these conditions, continues to contract with force and rhythm for some seconds. If the stethoscope be applied to the internal face of the stump, it permits us to hear at the moment of each contraction a sound that is exactly like the one which had been perceived in the nonmutilated. There is, however, a vast difference in intensity, the sound emitted from the experimental heart-muscle being very weak.

The contraction of the auricles is not considered at all as being a factor in the production of cardiac sounds. Repeated experiments have proved the auricular contractions to be inaudible.

Position of Valves and the Areas of Audibility.—The pulmonary and tricuspid of the right side lie nearer the surface than the aortic and mitral of the left.

The best point to hear the pulmonary valve is chiefly behind the third left costal cartilage. For the aortic valve it is behind the left half of the sternum, on a level with the third interspace. For the mitral valve it is behind the left half of the sternum, on a level with the fourth and upper border of the fifth cartilage. For the tricuspid valve, behind the lower fourth of the sternum, to the right of the middle line from the fourth right cartilage to a point behind the junction of the sixth right cartilage to the sternum.

Variations in Heart-sounds.—Increase in the intensity of the first sound of the heart is indicative of a more vigorous contraction of the ventricles, with, of course, greater tension of the auriculo-ventricular valves.

Increase of the second sound denotes a higher tension in the corresponding large arteries. The condition is usually demonstrative of overfilling and congestion of the pulmonary circuit. With equal intensity the muscular sound of the left ventricle is appreciably longer than that of the right.

Weak heart-sounds are indicative of a *feeble* action of the heart and usually denotes degenerations of the heart-muscle.

The first sound is very faint or not heard at all when the ventricular systole is weak. If the ventricle is hypertrophied the sound is low and booming; if the heart-muscle is dilated, the sound is high pitched.

The Coronary Arteries.—The heart-muscle, by reason of its almost constant activity, must be very generously supplied with blood to insure its proper nutrition. In it are found a system of arteries, capillaries, and veins, known as the coronary vessels.

The arteries going to the heart-muscle are two in number: the *right* and *left coronary.* They are the first branches of the aorta, and take their origin just above the level of the free margins of the semilunar valves. The diameter of the coronary arteries is that of a crow's quill. From these main vessels there proceed numerous branches which dip down into the heart-substance, dividing and subdividing as they go until a system of capillaries is formed.

The effete products are conveyed to the general circulatory system by the *coronary vein,* which empties its blood into the right auricle.

It, with its branches, is provided with valves, since every auricular systole interrupts the venous flow; the ventricular contractions, however, accelerate its flow. The coronary arteries are characterized by their very thick connective tissue and elastic intima, which perhaps accounts for the frequent occurrence of atheroma of these vessels.

The net-work of cardiac capillaries is very close and spiral vessels are found which supply blood in the change of form and position by the muscle-fiber. The coronary arteries do not anastomose.

Porter found the volume of blood passing through the coronary vessels is increased by an increase in either the force or the frequency of the heart-beats. The emptying of the intra-mural vessels of the heart by the contraction of the heart favors the flow of blood through the heart walls chiefly by the diminished resistance which the empty patulous vessels offer to the inflow from the aorta when the heart relaxes. This compression of the coronary vessels drives the blood into the right auricle. The relaxation of the heart-walls does not produce a noteworthy suction in the larger coronary vessels.

At the beginning of systole the blood rushes into the coronary arteries in the same fashion that it does into other arteries. However, later, during systole, the branches of the coronary arteries are so squeezed by the strong ventricular contractions that the passage of the blood is temporarily obstructed or even made to retrograde. Before the blood can recede to any extent, systole has ended and the blood then flows along as before.

It has also been found that, during the beginning of a ventricular systole, a cut into the coronary artery of a living animal causes a spurt of blood from the *central end* of the artery.

A shortening of the diastolic period lessens the nutritive supply to the heart. Diastolic distention of the left heart by "back pressure" lessens the coronary flow. These facts are of much practical import in diseases of the heart.

Pratt found that the vessels of Thebesius open from the ventricles and auricles into a system of fine branches that communicate with the coronary arteries and veins by means of capillaries and with the veins, but not with the arteries, by passages of somewhat large size. He also showed that with the coronary arteries absolutely cut off the mammalian ventricles may be maintained under proper conditions in rhythmic contraction for hours, by the blood through the foramina of Thebesius.

Ligation of both coronary arteries in the dog is followed by a decreased force and rate of the heart-beat, and often a series of independent contractions of the individual muscle-fibers, which are called fibrillary contractions, and finally complete arrest of the heart. Porter found that the whole dog's heart can recover from the fibrillary contractions by cooling the ventricles until all trace of fibrillation has disappeared and then bringing the heart back to the normal temperature by circulating warmed defibrinated blood through the coronary vessels.

In those cases of degeneration where disease of the coronary vessel-walls produces the condition known as atheroma, the symptoms of ligaturing and of sudden death occur because of the sudden arrest of the heart's action.

Dr. Ida H. Hyde found that the quantity of blood flowing through the heart is diminished by a greater internal pressure and a consequent distension of the heart even when it is beating.

The coronary veins have their outflow temporarily retarded by the contraction of the right auricles, an action partially contributed to by the valve of Thebesius. The coronary veins empty themselves when the auricles relax.

The frequency of the mammalian heart is changed but little by the quantity of blood flowing through the coronary arteries, but the quantity is of great importance, for the force of heart. If the heart has no work to do it has need of only a very small amount of blood.

Frequency of the Heart's Action.—During health the heart acts so smoothly and with so little concern on our part that there is required considerable self-attention before any differences are seen to exist. Its action, as studied from the throbbings (pulse) that are exhibited by some of the more superficial arteries, and each of which corresponds to ventricular systole, is found to lie in very close sympathy to the other great functions of the economy and is accordingly influenced by them. The average number of adult beats is 72 per minute. Even in health great deviation on either side of this standard may exist, depending upon age, sex, size, food, drink, exercise, posture, etc. That age and sex exercise an influence upon the frequency of the heart's movements must be remembered by the clinician when making his diagnosis. From the annexed table it will be noticed that just before birth the rate, as determined by the stethoscope, is very high, but gradually diminishes until very old age, when there is a slight increase. Sex is very influential, the female heart averaging about eight beats more per minute.

It has been noticed that the rule seems to be that *smaller* animals possess a greater amount of neuro-muscular activity than larger ones. Among human beings this is also applicable, shorter people usually having a pulse that is a trifle more rapid than taller people. Idiosyncrasies are frequently found which are at first very misleading to the diagnostician. Thus, the pulse of Napoleon I often did not exceed 40 beats to the minute, yet he was perfectly well. After each meal there is an increase of from 5 to 10 beats, while following very violent exercise the figures 140 or 150 may be reached.

During health there is found a nearly constant relation existing between the number of heart-beats and of respirations. This proportion is *four* heart-beats for *every single* respiration. Even when the number is very much increased from violent exercise or any other cause, the proportion still remains constant. Pathological conditions usually alter this relation. Landois gives the following results:—

In male adults the pulse-rate is 72, in females 80.

Age.	Pulsations per Minute. Male.
Fœtal	130 to 140
1 year	120 to 130
2 years	105
3 years	100
4 years	97
5 years	94
10 years	90
10 to 15 years	78
15 to 50 years	70
80 to 90 years	80

Pathological Action.—Increasing the rate of the heart does not mean an increase in work, for the output per systole is proportionately lessened. A dilated heart must use more force that it may expel the blood than one of normal capacity; hence it enlarges. Dilatation and hypertrophy usually go together.

In physiological conditions the different cavities of the heart expel equal volumes of blood in the same time. Not to do so would cause an unusual effort by the heart-muscle and the usual heart failure.

The increased frequency of the heart in children is probably due to want of inhibitory power in the vagus. The erect position increases the heart-beat, because the attitude makes the blood-pressure fall and the heart beats more rapidly to make up for it.

Slow pulse or bradycardia may be due either to lessened excitability of the cardiac muscle or an exaggerated inhibition by the vagus, seen in recovery from enteric fever and pneumonia. Slow pulse may be due to high arterial tension, stimulating the center of the vagus.

Emotional causes acting upon the accelerators will not raise the heart-beat beyond 120 per minute. Shortening of diastole is injurious to the heart, as it is the only resting time for the heart.

Work of the Heart.—When a force produces acceleration, or when it maintains motion unchanged in opposition to resistance, it is said to do *work*. To convey an impression of the amount of work done by any machine, it is usual to express its efficiency in terms of *work-units.* This is a comparatively easy task when attempted in the physical world, but becomes extremely difficult when one attempts to express in terms of work-units the force of the heart's action. The work of the heart—central pump, that it is—is so hard to reckon in view of the ill-defined data that we are able to obtain as to the resistance which it overcomes, and from the fact that different portions of this human machine are known to exert different degrees of force.

Anatomical differences, then, in the heart musculature permit the conclusion that the left heart, the walls of which are thicker, has more force than the right heart. It is reasonable to state from these premises that where the ventricular walls are three times thicker in one-half of the heart than they are in the other, that one must have a thrice greater systolic force than the other half.

The work of the heart is usually expressed in kilogrammeters. A kilogrammeter is equal to 7.24 foot-pounds. To estimate the work of the heart according to Dr. Leonard Hill, the mean pressure and velocity in the aorta and the volume of blood ejected by the ventricle must be obtained.

If W be the work done during systole of the left ventricle in gram centimeters; Q, the volume of the output in cubic centimeters; M, the mass of the output in grams; P, the specific gravity of the blood ($\therefore M = PQ$); V, the mean velocity in the aorta; H, the mean aortic pressure in grams per centimeter; g, the acceleration due to gravity = 981 centimeters per second, then

$$W = QH + \frac{MV^2}{2g}$$

$$\therefore W = QH + \frac{PQV^2}{2g}$$

The mean aortic pressure may be put down as 12 centimeters of mercury (specific gravity of mercury = 13.5). The volume of the systolic output is about 110 cubic centimeters. Substituting these data in the above equation one obtains:—

$$W = 110 + 12 + 13.5 + \frac{1.05 \times 110 \times 32^2}{2 \times 981} = 17.880 \text{ gram centimeters.}$$

If in the case of the right ventricle the mean pressure in the pulmonary artery be taken to be 4 centimeters of the mercury, the work of that ventricle will be one-third of that of the left ventricle. Thus, the total work of each systole of the heart will be 17,880 × $\frac{4}{3}$ = 23,640 gram centimeters, and the total work of the heart will be per day about 24,000 kilogrammeters, or 1,000 kilogrammeters per hour, or the equivalent of about $\frac{1}{50}$ of the whole amount of heat produced in the body.

When the ejection of blood from the ventricle is retarded by the aortic valves, permitting regurgitation or by a high arterial tension, then there is a strain upon the cardiac muscle which is met by increased contraction. In the muscle of the heart the greater the resistance, up to a certain point, to contraction, the stronger the force of contraction. If the heart has continuously to meet these resistances, then its muscle hypertrophies and compensates for the defective valve in order to properly carry on the circulation.

INNERVATION OF THE HEART.

If the heart be removed from the chest or all of its nerves be severed, it will still continue to beat for a variable time, dependent upon the class of animal operated upon. In the case of the frog and other cold-blooded animals the beating of the heart will continue for hours under favorable conditions. From this it would seem that there must reside within the heart itself some mechanism whereby the rhythmical movements of the heart are maintained.

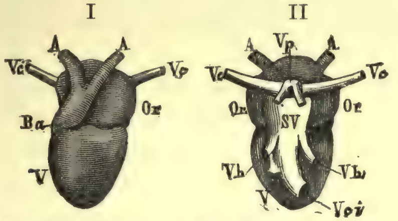

Fig. 75.—Heart of the Frog. (LIVON.)

I. Anterior view. II. Posterior view. *A*, *A*, Aortæ. *Vc*, Superior vena cava. *Or*, Auricle. *V*, Ventricle. *Ba*, Aortic bulb. *SV*, Sinus venosus. *Vci*, Inferior vena cava. *Vb*, Hepatic vein. *Vh*, Pulmonary vein.

Like every other organ of the body, the heart receives its proper quota of nerve-supply, through whose medium are conducted certain impulses from without and by whose influence its rhythm may be *altered*.

Cardiac Ganglia.—This internal mechanism has been chiefly studied in the frog, where there exists in the heart *three distinct ganglia:* Remak's, Bidder's, and von Bezold's. From the cells of these ganglia there are discerned numerous small fibers which form a plexus over the surface of the auricles and upper portion of the ventricles.

Remak's ganglion is seen at the orifice of the superior vena cava or sinus venosus. *Bidder's* is located at the junction of the auricles and ventricles in the auriculo-ventricular groove. *Von Bezold's* ganglion has its seat in the interauricular septum.

The heart of a mammal differs from that of an amphibian only in that there are several groups of ganglia in the mammals, while but one exists in the amphibians. However, these several ganglia of the mammal are believed to be automatically and physiologically equivalent to the homologous single ganglion or group of ganglia of the amphibian. The same general laws may be applied to both.

Cause of Cardiac Rhythm.—The rhythm of the ventricle is a property of the *cardiac muscle.* In the maintenance of this rhythm the nervous system does not intervene except as an ordinary excitant of muscle. It is known that, if the apex of the frog's heart be cut away, it is then separated from all ganglia. The excised portion does not beat spontaneously, while the rest of the heart, the auricles and the base of the ventricles, continue their rhythmical action. Thus it seems that the ventricles can contract under the persuasion of irritations which arise in them.

If now the isolated and immovable portion of the heart be placed under a cardiograph and subjected to opening of the induction current, there will result a pulsation from each isolated induction shock.

It is a remarkable fact that, if this same excised portion be excited by frequent breaks (at least thirty per second), the muscle *beats rhythmically.* Ordinary striped muscle responds to isolated and separate breaks of the induction current by manifesting isolated contractions. Heart-muscle cannot be tetanized.

Hence this observation would force us to the conclusion that the heart's rhythm does not depend upon the ganglionic cells of the heart. The rhythm is the property of the cardiac muscle to react to the frequent excitations which it receives.

In this respect cardiac muscle is completely differentiated from ordinary striated muscle. It is a mistake to seek to make the rhythmical property of the cardiac muscle a property of ordinary muscle.

Theory of Cardiac Rhythm.—Numerous experiments have been performed upon the hearts of animals (the frog chiefly) for determining the causes and means of control of the rhythmical movements of the heart. The experiments consist, for the most part, of *ligaturing* various portions of the heart, and are performed by tightening and then relaxing the ligature so that the physiological connection is destroyed, while its anatomical and mechanical functions are still intact. The most important, as well as best known, of the ligature experiments is the one known as:—

Stannius's Experiment.—If the sinus venosus of the frog's heart be separated from the auricles by the application of a ligature, then the auricles and ventricles will remain quiet in diastole, while the veins and the remainder of the sinus continue to beat. If a second ligature be applied at the junction of the auricles and ventricle, the usual sequence is for the ventricle to begin to beat again while the auricles continue to remain in their diastolic rest. Though the two, sinus venosus and ventricle, continue to beat, their motion is not rhythmical, the ventricular movements being considerably slower. In every case the quiescent portion can be made to give single contractions by stimuli, either mechanical or electrical. Thus, when the ventricle remains quiet after the first ligature, it may be made to give single contractions by pin-pricks.

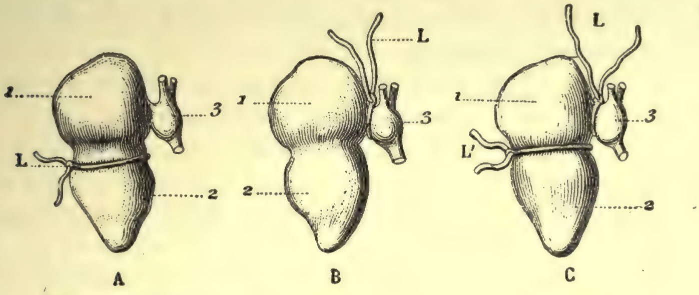

Fig. 76.—Schema of Ligatures of Stannius. (Hedon.)

A. Ligature below the auriculo-ventricular groove (*L*); the sinus venosus (3) and the auricles (1) continue to beat, but the apex of the isolated ventricle is arrested.

B. Ligature of *L* to sinus (3), which continues its rhythmical beats; 1 and 2 are arrested in diastole (seventh experiment of Stannius).

C. After the ligature (*L*) as in B, a second ligature (*L'*) is placed around the auriculo-ventricular groove; the ventricle, which was originally arrested, after some rhythmical contraction, is again arrested (tenth experiment of Stannius).

There are two explanations of the effects of Stannius' ligature, known as the nerve theory or neurogenic theory of the cause of the heart-beat, and the muscle theory or the myogenic theory (sinus theory) of the heart-beat. I shall first take up the neurogenic theory.

Neurogenic Theory.—To explain the experiment of Stannius it has been asserted that Remak's and Bidder's ganglia are motor and von Bezold's is inhibitory; that the motor influence of Remak's and Bidder's is greater than the inhibitory influence of von Bezold's; hence, in the absence of all ligatures, the heart beats. That the motor power of Bidder's is less than the inhibitory power of von Bezold's; consequently, the first ligature cutting off the motor power of Remak's, the auricle and ventricle stand quiescent, while after the second ligature, cutting off also the inhibition of von Bezold's ganglia, the ventricle, actuated by Bidder's ganglia alone and unopposed, again commences to beat.

Dogiel and Archangelsky, in a frog's heart, have extirpated the ganglia of Bidder, the intraventricular ganglia, and the ganglion cells and nerves which lie about the auriculo-ventricular groove, and found that the ventricle lost the power to rhythmically contract, although its muscle and nerves were retained up to the ganglion cells, which had been removed. In such a heart, robbed of its ganglion cells, the law of Bowditch, that a minimal irritation is at the same time a maximal one, fails, for the cardiac muscle gave varying heights of contraction with varying strength of the electrical current.

Marie Imchanitzky, working in Kronecker's laboratory, found in a lizard, where neither muscle-bridges connected the auricle to the ventricle, nor any bundle of muscle-fibers in the septum corresponding to that of His, that ligation of the nervous cords which are the only connection between the auricles and ventricles, made the auricles beat 10 per minute and the ventricles 3, then it was 14 to 6. Besides these nervous cords, only connective tissue can be noticed between the auricles and ventricles. Here there is a purely neurogenic origin of co-ordination of the heart-beat.

Carlson has made numerous experiments upon the crab's heart, which prove the neurogenic theory of its heart action. The neurogenic theory has received some support by experiments upon the heart of warm-blooded animals.

Kronecker and Schmey found that a needle thrust into the heart at the lower border of the upper third of the septum produced fibrillary contractions, which Kronecker believed was due to a puncture of the co-ordinating nerve center situated at that point, or to his later theory that the needle irritates a vasomotor center which produces a deficient blood-supply to the ventricle.

Myogenic Theory.—This theory is the one generally held by the majority of physiologists. The nerveless apex of a frog's heart has been kept twenty-one days and it was still able to contract upon stimulation. In such a preparation all cut nerves should be degenerated. Ammonia and weak acids excite the muscle of the apex, whilst glycerine which excites nerve, had no effect upon the apex. It must be inferred that the heart-muscle has irritability and contractility independent of the nerves in it. In the heart, stimuli pass in all directions from ventricle to auricle or from auricle to ventricle; this is not a property of nerve-fibers. Engelmann by zigzag cuts probably cut all nerve-fibers, yet conduction ensued from end to end of the muscle.

In the myogenic theory, the heart-muscles have the property of automatic rhythm, and the power and supremacy is greatest at the venous end of the heart. Hence this part of the heart contracts first and the wave spreads to the auricle and then to the ventricle.

Porter has found that the apex of a dog's heart, which histologists tell us has no nerve-cells, when fed by its nutrient artery with warm defibrinated blood-beats for several hours.

According to Gaskell and Engelmann, the nerve-ganglia do not play any part in the movements of the frog's heart. According to their idea the sinus sends out impulse-waves through the muscular structure of the heart. When the first Stannius ligature is applied it blocks the waves running from the sinus to the right auricle. Here the sinus continues beating, but the remainder of the heart is quiet. If, now, you tie a ligature in the auriculo-ventricular groove of this quiescent heart, then the ventricle beats. The ligature or compressor at this point is said to stimulate the ventricle.

In mammals the sinus venosus of the frog has been included in the right auricle at the point of entrance of the venæ cavæ, and is thus directly continuous with the auricular wall.

It was formerly supposed that there was no muscular connection existing between the auricles and ventricles, but the bundle of His has been found to extend from the auricles to the ventricles.

This bundle is about 2 inches in length, about $^1/_{10}$ of an inch in width, and about $^1/_{16}$ of an inch in thickness. Tawara has found a nervous network in this bundle of His.

Auriculo-ventricular Bundle of His.[1]—According to Tawara, this bundle starts in the vicinity of the anterior edge of the coronary vein, running forward on the right side of the auricular septum below the oval foramen, closely hugging the auriculo-ventricular septum. Just above the median flap of the tricuspid valve this bundle forms a node and from this node a process arises which pierces the fibrous septum, runs along dorsal to the ventricular septum and divides into two main branches, passing obliquely downwards, on each side of the septum of the ventricle under the endocardium. The right and left branch of the main bundle, each enclosed in a connective-tissue sheath of its own, isolated from other muscles, pass a long way down the septum and in the lower third of ventricular cavities, with the trabecula, enter the anterior and posterior papillary muscles. When they get to the papillary muscles, some of the fibers pass beyond them, enter the parietal wall of the ventricle, where they send branches upwards and downwards under the endocardium and lining of the interior surface of the ventricles to fuse with the cardiac muscle. The auriculo-ventricular bundle throughout its whole extent is peculiar as regards structure when compared with ordinary cardiac muscle-fibers by the fact of a small development of sarcoplasm. The embryonic fibers described by Purkinje, of Breslau, in 1845, in the sub-endocardial layers of the ventricle are really the main branches of the ventricular part of the auriculo-ventricular bundle. The Purkinje fibers are pale in stained preparations on account of the diminished amount of fibrillary substance and by their well-marked connective-tissue sheath are easily distinguished from other ventricular fibers. Moenckeberg in the main facts corroborates the findings of Tawara.

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[1] British Medical Journal, 1906, p. 1107.

On the inner surface of the ventricles have been found tendinous structures. Tawara thinks they are nothing else than branches of the auriculo-ventricular bundle, which are normal in many lower animals but abnormal in man. Moenckeberg has divided the so-called "tendons" into four groups, as regards the left ventricle: (1) fibers which contain no muscular fiber, actually abnormal tendons; (2) fibers which are ventricular muscle fibers; (3) fibers which are exclusively of the auriculo-ventricular bundle; (4) fibers which are ventricular and mixed with auriculo-ventricular bundle. The first two kinds do not have anything to do with the bundle of His; the last two are fibers of the left branch of the auriculo-ventricular bundle which are abnormal.

Keith and Flack have shown the existence at the junction of the superior vena cava and the right auricle of a ring of peculiar muscle-tissue which they named the sino-auricular node and which has a structure similar to that of the auriculo-ventricular bundle and node, and is furnished with a separate blood supply from both coronary arteries. It also contains nerve-cells and their fibers. The connection between this ring of tissue and the auriculo-ventricular node is still uncertain, but appears to be by means of the auricular muscle-fibers.

Conduction of the auricular impulse is much slower in the bundle of His than in the other muscle-fibers of the heart. Clamping this bundle in animals varies its conductivity. The experiments of Hering and Erlanger have shown that along this "auriculo-ventricular bundle of His" the wave of stimulation is carried from the auricle to the ventricle.

The time of the normal block to the transmission of the wave of impulses from the auricle to the ventricle is about one-fifth of a second. With very little compression of the auriculo-ventricular bundle in animals by the clamp of Erlanger there is simply an increase of the normal pause during which the wave from the auricle reaches the ventricle. This delay may be caused either by a slow transmission of the auricular impulse through the bundle of His which has been compressed, or to a decrease in the intensity of the impulses

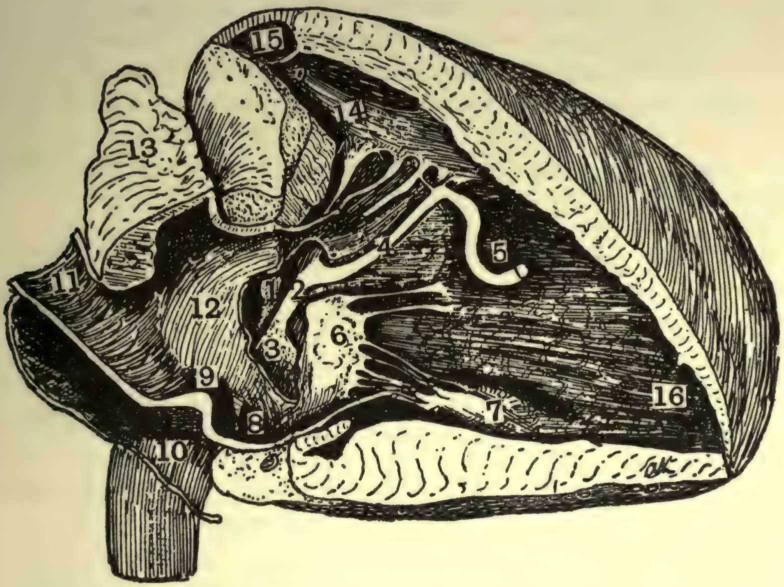


Fig. 76a.—Right Auricle and Ventricle of the Calf. (KEITH.)

1, Central cartilage. 2, Bundle of His or the auriculo-ventricular bundle dividing into right and left septal branches (*av* bundle). 3, *av*, Node. 4, Right division of the bundle of His. 5, The right branch of the bundle of His breaks up into smaller strands which pass to the papillary muscles (4 and 6) seated on the septum. Arising from the group of papillary muscles are the terminal branches of the bundle of His, which, especially on the right side, takes the form of the small "so-called moderator" bands and pass out to all parts of the ventricular wall and fuse with the ventricular muscles. 8, Orifice of coronary sinus, which is a good guide to the position of the *av* node, which lies below and to the right. Microscopically the *av* node has peculiar branched cells—the main bundle contains large pale cells with large nuclei and the peculiar Purkinje cells found in the septal divisions and their terminal ramifications, especially in the "so-called moderator" bands. The sino-auricular node portion of sinus venosus is found where the superior vena cava joins the tænia terminalis of the right auricle. This sino-auricular node is identical in structure with the *av* node. These nodes are in muscular connection with each other, probably have the same function, and are remains of the primitive cardiac tissue.

coming from the auricle, with consequent lengthening of the latent period of the ventricular muscle. At this stage of compression of the bundle of His it is usual for the time between the auricular and ventricular systoles to lengthen until finally the ventricle fails to be fired off by the impulses from the auricle, so that we have a loss of a beat of the ventricles to every eight, or ten, auricular systoles. If the clamp is tightened more, then we have a failure of the ventricle to contract with every other auricular beat; here the rhythm is 2 to 1. Further compression by the clamp causes, for every three or four auricular beats, a single ventricular contraction, a rhythm of 3 to 1 or 4 to 1. These cases of partial heart-block are to be explained by the fact that after each contraction of the ventricle it experiences a fall in irritability. But by its rest, there is an increase in irritability and then the ventricle is fired off by the auricular impulses. A reduction in the efficiency of the wave of excitation from the auricles may ensue from the compression of the bundle of His; hence the ventricles will not be fired off until they have increased their irritability by rest to respond to the weakened excitation from the auricles. When a complete heart-

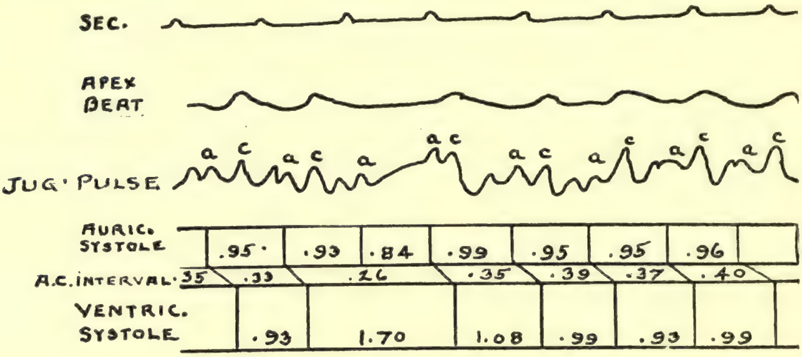


Fig. 77.—A Case of Heart Block.

The uppermost line represents the time in seconds, the next line the apex beat, and the third the jugular pulse, showing the transmitted carotid wave, *c*. The third auricular contraction is not followed by any contraction of the ventricle. The diagrammatic figure below shows the time of the auricular systole by the upper verticals, the time of the ventricular systole by the lower verticals, and the *a-c* period by the obliquity of the lines connecting these. Numerals in this diagram represent fractions of a second. Notice the shortening of the *a-c* period after the heart-block, and how this lengthens the succeeding ventricular period. In the venous pulse, *a* represents the auricular contraction and *c*, the "carotid pulse" (ventricular contraction), or, more correctly, the closing of the tricuspid valve. The *a-c* interval normally does not exceed a fifth of a second, but where conduction is poor in the bundle of His, it may be prolonged to two-fifths or more. (Hewlett.)

block is produced, the ventricles cease to beat for a time, the auricles, however, beating their usual rate. But after a pause from one to eighty seconds the ventricle resumes its beat and gradually increases its frequency. The stoppage of the ventricles is due to a want of impulses from the auricles to fire them off. The subsequent slow beat of the ventricle is due to an inherent power in the muscle of the ventricle to beat in a rhythm. In cases of complete heart-block by compression of the auriculo-ventricular bundle, irritation of the accelerator nerves increases the rate of the auricles and ventricles, whilst irritation of the vagus inhibits the auricle but not the ventricle. Hering states that the vagus also slows the ventricle in this case.

Similar cases of heart-block in man have taken place in the cases of the disease known as Stokes-Adams. In a case of this kind Dr. Alfred Stengel has discovered an atheromatous lesion in the bundle of His. Clinically we may estimate the time taken in the conduction of the wave of contraction from the auricles to the ventricles by the duration of the "A-C" interval from the venous pulse in the jugular, where "A" stands for the auricular contraction and "C" for the pulse in the carotid (contraction of ventricle). Normally the A-C interval is about 0.20 of a second, but where the conductivity is poor it may be lengthened to 0.40 of a second or more.

If conduction of the impulses from the auricle cannot travel to the ventricles, as in the heart-block of Stokes-Adams disease, then we have a beat of the auricle but not of the ventricle. The next wave of stimulus, however, passes over the bundle with unusual rapidity and the A-C period is shortened. Only occasional impulses may fail to pass the bundle of His, and if heart-block is complete we have the ventricles beating 30 per minute independent of the auricles, which beat 84, as Erlanger observed in Stokes-Adams disease. H. E. Hering, in contradiction to several observers has shown that the papillary muscles contract before the apex of the heart, as the bundle of His runs first in the papillary muscles and then gives off branches.

A depression of conductivity results in a lengthening of the A-C interval, an occasional dropping out of the ventricular systole, a 2 to 1 rhythm or a 3 to 1 rhythm, and a complete block, the auricular rhythm being independent of and differing from the ventricular.

Pathological and Pharmacological Actions.—The alternating pulse, pulsus alternans, in which large and small pulse-beats alternate is a good example of defect in contractility. In the cases of Stokes-Adams disease digitalis can produce partial heart-block, whilst atropin increases the auricular beats but leaves the ventricular beats unchanged.

CARDIAC NERVES.

Engelmann has divided the action of the vagi and accelerator nerves on the heart into four different heads: (1) The inotropic influence, positive or negative, affecting the force of the contraction. (2) The chronotropic influence, positive and negative, affecting the rate of contraction, positive chronotropic actions producing an acceleration. (3) Bathmotropic influence, affecting the irritability of the muscular tissue and may be positive or negative. (4) Dromotropic influence, positive or negative, affecting the conductivity of the tissue. Both cardiac nerves, when irritated, are slow in acting; that is, have a long latent period. Both cardiac nerves can be fatigued, and if in a cold-blooded animal one vagus has been irritated until exhausted, then irritation of the peripheral end is without effect. The vagus, according to Gaskell, is an anabolic nerve, as it retards chemical changes in the cardiac muscle. The accelerator, according to him, is a catabolic nerve, for it increases the chemical changes in the muscle.

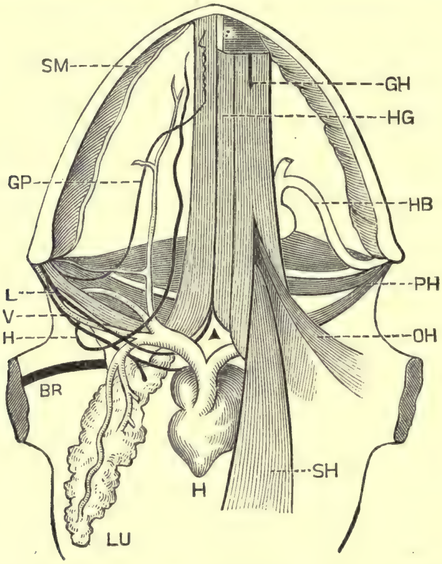


Fig. 78.—Course of Vagus Nerve in Frog. (STIRLING.)

SM, Submentalis. *LU*, Lung. *V*, Vagus. *GP*, Glosso-pharyngeal. *HS*, Hypoglossal. *L*, Laryngeal. *PH*, *SH*, *GH*, *OH*, Petro-, sterno-, genio-, and omohyoid. *HG*, Hypoglossus. *H*, Heart. *BR*, Brachial plexus.

The change of rate and rhythm of the heart in disease may be in the muscle or the nervous supply of the heart. Thus the propagation of stimuli over the heart (dromotropy), as well as the contraction of the cardiac muscle (inotropy), may be abnormally augmented or decreased. The regular initiation of stimuli (chronotropy) may vary, as well as the ability of the heart to respond to these stimuli (bathmotropy.)

Extracardiac Nervous System.

The extracardiac nervous system is composed of the cardiac branches of the *vagus,* together with the cardiac branches of the *sympathetic.*

Vagus-path.—The vagus arises chiefly from the nucleus ambiguus in the medulla oblongata. It descends in the neck, giving off near the origin in the neck of the superior and inferior laryngeal nerves the superior cardiac branch, and near the origin of the inferior laryngeal in the thorax, the inferior cardiac branches, which contain the majority of the cardio-inhibitory fibers. The inhibitory fibers belong to the autonomic system, are pre-ganglionic and end around the sympathetic ganglia in the heart, whilst the post-ganglionic fibers run from here to the cardiac muscle-fiber.

As has been previously stated, the immediate cause of the *rhythmical contractions* of the heart lies in the protoplasm of the muscle-cells themselves, but the *rate* and *force* of its beats are influenced by impulses reaching it through the central nervous system. The effects of these impulses are twofold: *inhibition,* or diminution in the rate or force of the heart-beat, and *acceleration,* or increase in the rate or force. Both the inhibitory and accelerator centers are located within the medulla, from which fibers leave the cranium and reach the heart. Of these efferent fibers of the vagus, the inhibitory ones are most prominent.

Inhibitory Nerves of the Heart.—Section of the vagus in the cat and rabbit is not followed by much increase in the rate of the heart-beat; in the dog and man the increase of rate is much greater. In children the inhibitory power of the vagus is very weak, and they can bear doses of atropin much better than adults because there is not much increase of the rate of the heart after the use of it. These facts lead to the conclusion that in warm-blooded animals the vagi are in a state of constant activity with an inhibitory control over the heart.

When all the extra cardiac nerves in the dog were cut on both sides, and at the same time the inferior cervical and the superior cervical ganglia were extirpated and the animal survived eight months, the number of the beats of the heart was not markedly changed. If, however, the dog was made to walk more than a kilometer, then serious cardiac trouble ensued. The permanent regulation of the work of the heart is then conditioned on the central nervous system and the sympathetic ganglia. If the vagus is divided and the peripheral end irritated, as the Weber brothers did in 1845, then we have an arrest of the heart in diastole. This inhibitory action of the vagus is seen in all animals. Czermak, who had an exostosis on the cervical vertebra, by pressing his finger on the right vagus, mechanically irritating it, could at any time slow the heart and even bring it to a complete arrest for a moment. The right vagus often has a more powerful inhibitory effect than the left. In the slowing of the heart by irritation of the vagus the diastole is lengthened, both auricles and ventricles are stopped, and the heart dilates and is swollen with blood. This inhibitory effect on the heart lasts some time after the irritation of the vagus stops. During this inhibitory action by irritation of the vagus the heart's excitability is diminished, its contents are not so great and the blood-pressure falls. The slowing of the ventricle is supposed to be due to an inhibition of the auricle, which slows or does not permit the usual exciting impulses to travel from it to "shoot off" the ventricle. But it has been shown by Tigerstedt that dividing the connection between the auricle and the ventricle does not bring on a pause, as it should if the ventricular contractions were due to impulses coming from the auricle. It is probable then that inhibition is exerted mainly on the auricles and in part upon the ventricles. Erlanger with a clamp on the auriculo-ventricular bundle of His found that stimulation of the vagus only affects the auricle in that case.

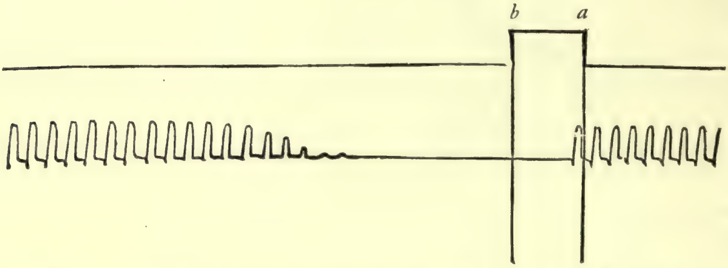


Fig. 79.—Tracing by Lever Attached to Frog's Heart on Stimulation of the Pneumogastric Nerve. (Foster.)

a-b shows time of stimulation by electricity. As the tracing shows, the heart's movements were arrested for some time.

It makes no difference whether one irritates the center of the pneumogastrics, their trunk, or peripheral ends within the heart, the same result follows: there is a diminution in the number of the heart-beats.

Peculiarities.—Some of the points of peculiarity of the vagus and its action are: 1. The heart is arrested in diastole; so that the slowing depends upon the period of diastole. 2. The irritation of one nerve alone acts upon the two sets of inhibitory ganglia in the heart by reason of association fibers. 3. After the arrest of the heart by excitation of the vagus the heart begins its contractions first in the auricles.

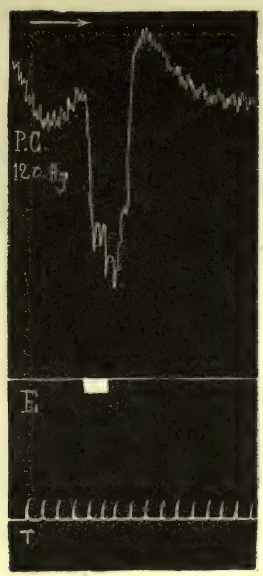


Fig. 80.—Arrest of the Heart of a Rabbit by Irritation of the Peripheral End of the Pneumogastric in the Neck. (Gley.)

PC, Carotid pressure equals 12 centimeters of mercury. *E*, Excitation of the nerve by an induction current. *T*, Time every 2 seconds.

Cardio-inhibitory Reflexes.—A tap upon the abdominal wall is able to throw the pneumogastric into greatly increased action; so that the heart is often stopped and death ensues. In this case the sympathetic nerves of the solar plexus convey the impression up the spinal cord to the center of the pneumogastric in the medulla. From the medulla the impulse is sent down the inhibitory fibers of the pneumogastric, which causes arrest of the heart. The arrest occurs always in diastole, never in systole.

All of the sensory nerves of the body have a reflex relation to the pneumogastrics. Even pinching the skin of some fishes is sufficient to stop the heart. Irritation of the branches of the fifth nerve in the rabbit by ether and other vapors can stop the heart. There are reasons to believe similar results can occasionally be obtained in man.

SWALLOWING FLUIDS.—Experimenters have demonstrated that swallowing interferes with or even may abolish for a short time the cardio-inhibitory action of the vagus. By reason of this the pulse-rate is greatly increased. *Sipping* a wineglassful of water will raise the pulse-count 30 per cent. In this way water can be made to behave as a powerful cardiac excitant. The course of the impulse is along afferent fibers of the nerves supplying the œsophagus to the cardio-inhibitory center, whose tonus is reduced.

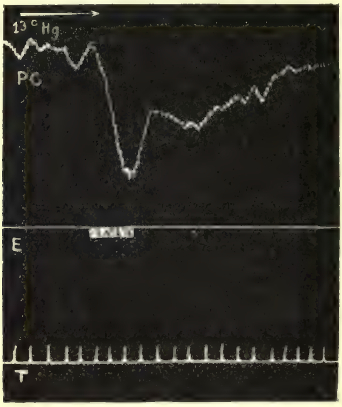
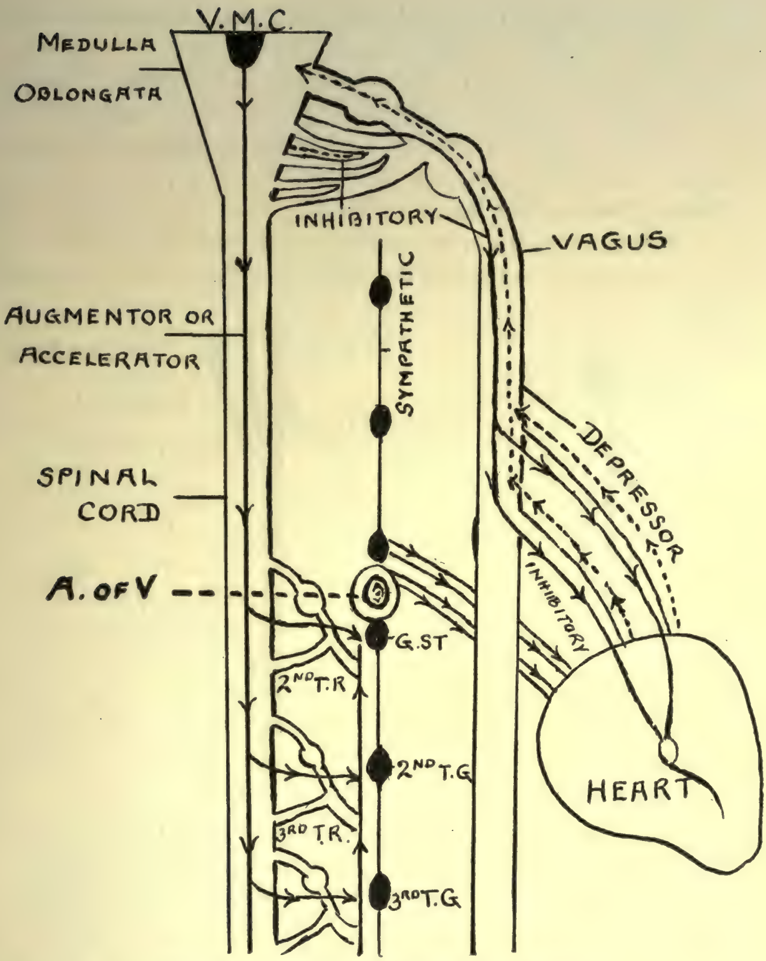


Fig. 81.—Irritation of Nervus Depressor in a Rabbit, Causing a Fall of Arterial Tension. (GLEY.)

PC, Carotid pressure. *E*, Time of irritation of nerve by the induced current. *T*, Time recorded every 2 seconds.

Pathological Action.—In disease we often have a slow pulse from inflammatory affections of the peritoneum. We can distinguish better if a slow pulse is due to increase of the inhibitory power of the vagus by giving a dose of atropin, which will accelerate the pulse. If the slowing is due to weak heart-muscles, as after pneumonia or typhoid fever, the atropin will be without effect. The vagus center can also be unduly excited by depressing emotions. As afferent impressions can either excite or inhibit the vagus center, we can have from sensory irritation a rapid pulse, as a soldier suddenly startled by an explosion of a gun. Vagus acceleration can never be more than 150.


V.M.C.
MEDULLA
OBLONGATA
INHIBITORY
VAGUS
SYMPATHETIC
AUGMENTOR OR
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SPINAL
CORD
A. OF V
INHIBITORY
G.ST
2ND T.R
2ND T.G
3RD T.R.
3RD T.G
HEART

Fig. 82.—Innervation of Heart. (POWELL.)

VMC, Vasomotor center. *A of V*, Annulus of Vieussens. *GSt*, Ganglion stellatum (First thoracic). *2dTG*, Second thoracic ganglion. *3dTG*, Third thoracic ganglion. Vagus is denoted by continuous lines—arrows toward heart. Depressor nerve is represented by dotted points—arrows from heart. In man the cardiac accelerator branches travel to the heart from the annulus of Vieussens and cervical sympathetic.

If the beats are more than this, say 200 per minute, there must be a temporary dilatation of the heart.

When the irritated vagus arrests the heart the first succeeding contractions are stronger or more numerous than previously, and the work of the heart is greater. An excess of carbonic acid in the blood excites the centers of the vagus and slows the heart. Increase of intracranial pressure lessens the rate of the heart.

Death from plunging into cold water is a case of reflex inhibition from the nerves of the skin. Irritation of the gastric mucous membrane is also an example of a sensory irritation depressing the cardio-inhibitory power of the vagus, the heart beating faster.

Afferent Nerve of the Heart. (Depressor Nerve of Ludwig and von Cyon.)—This nerve in the rabbit usually arises from two branches, one from the trunk of the vagus and the other from the superior laryngeal.

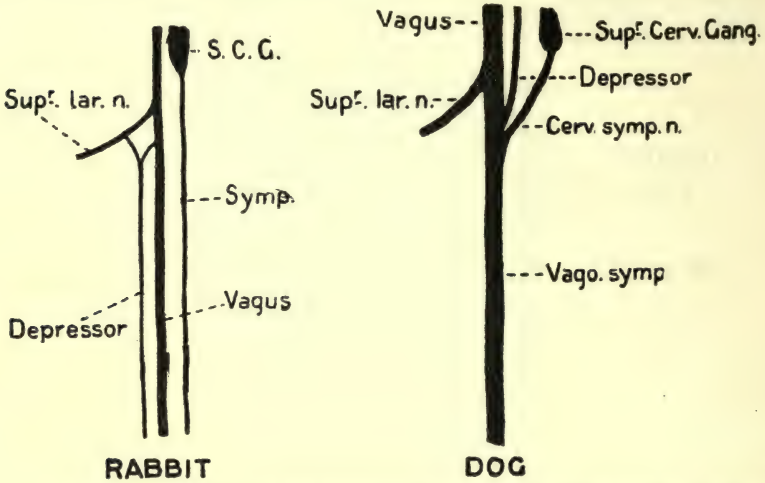

Fig. 83.—Diagram of the connections of the Depressor Nerve in the Rabbit and Dog, according to Cyon. It will be noticed that in the latter animal the depressor nerve runs in the vagus trunk for the greater part of the course. (Starling.)

It ends in the heart, and, according to some, in the aorta's origin. It is found in man and other animals. When its central end is stimulated, there is a fall of arterial tension to about half its former level. After the stimulation is arrested, the tension returns to normal. With this fall of arterial tension the beats of the heart are slowed; but if the vagi are divided, there is no change in the frequency of the heart, which shows that the lessening of the number of heart-beats is due to stimulation of the cardio-inhibitory center. Even after curarization, irritation of the central end of the depressor lowers the arterial tension. If the splanchnics are previously divided, stimulation of the depressor still has some effect.

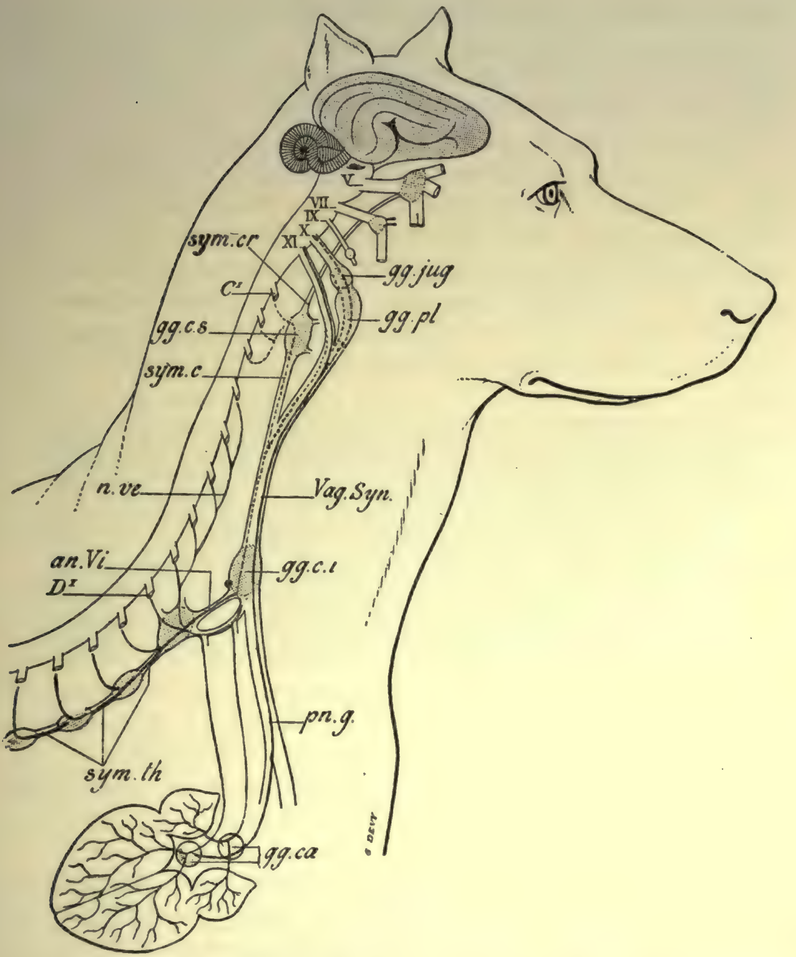

Fig. 84.—Schema of Innervation of the Heart of a Dog. (Morat.)

gg.ca, Cardiac ganglia in which the cardiac nerves terminate. *gg.ci*, Inferior cervical ganglion. *gg.cs*, Superior cervical ganglion. *gg.pl*, Plexiform ganglion. *sym.th*, Thoracic sympathetic. *an.Vi*, Ansa Vieussenii. *pn.g*, Pneumogastric. *n.ve*, Vertebral nerve. *Vag.symp.*, Vago-sympathetic. *sym.c*, Cervical sympathetic. *sym.cr*, Prolongation of the sympathetic in the skull. C^1, First cervical pair. D^1, First dorsal pair. *X*, Origin of the pneumogastric. *XI*, Bulbar origin of the spinal accessory.

Porter and Beyer have shown that it dilates the arterioles throughout the body, and especially those blood-vessels innervated by the splanchnics. Excessive repletion of the heart stimulates the endings of the depressor nerve in the heart. These afferent impulses inhibit the main vasomotor center and permit the arterioles to dilate, and, opening the flood-gates, thus relieve the systolic strain of the muscular fibers of the heart. The depressor nerve is not in constant action and is not easily fatigued.

It has been stated that the depressor nerve acts like a safety-valve to the heart. Sewall and Steiner found on division of the depressor nerves that with few exceptions the blood-pressure rose 1 to 3 centimeters of mercury. This would seem to indicate a tonic action of these nerves. They also clamped the carotids in rabbits, and this anæmia of the medulla stimulated the vasoconstrictor center and elevated blood-pressure. If, however, they divided the depressors and then occluded the carotid arteries, the rise of arterial tension was much greater. These data prove in the first experiment that the activity of the depressors prevented a great rise of pressure by the inhibition of the vasoconstrictor center and necessarily dilatation of the arterioles of the splanchnic area.

Von Cyon has shown that iodothyrin augments the irritability of the depressor nerve.

The depressor is greatly called into play in the heart of the bicycle-rider, where the abdominal reservoir of blood is compressed by the active abdominal muscles, and the blood is driven into the thoracic cavity and the heart is swollen with blood. The depressor cannot well dilate the abdominal vessels, for they are compressed in bicycle-riding by the violent compression of the muscles of the abdomen.

After an injection of pyocyanine, irritation of the depressor fails to lower blood-pressure. After the use of strychnia, the irritation of the depressor, causes a rise instead of a fall of arterial tension.

This nerve facilitates the escape of blood from the ventricles. At the same time it indirectly reduces the flow of blood in the auricles and the work of the heart lessens. The slow heart-beat contributes to diminish the work of the heart. The defence of the heart from excess of intra-cardiac pressure is the slowing of the heart and the vaso-dilation especially of the intestinal arterioles.

Accelerators.—The accelerators act upon the tonus and rhythm of the heart. In 1866 E. and M. Cyon proved that in a curarized dog with the depressors, vagi, cervical sympathetics and splanchnics divided that electric irritation of the cut cord was followed by a considerable acceleration of the heart without a change in blood pressure. The increase of heart-beats often amounts to 20 per cent. In this experiment the cord must exert its influence on the heart through the inferior cervical and the first thoracic ganglia. After they extirpated these ganglia, irritation of the cord caused no change in the number of heart-beats.

The accelerator nerves have their origin in the medulla oblongata and pass out from the spinal cord through the anterior roots of the second, third and fourth dorsal spinal nerves; then by the white rami to the stellate or first thoracic ganglion, and then by the annulus of Vieussens to the inferior cervical ganglia and thence to the heart, either to its cardiac plexus or more probably to the cardiac muscle. In the frog the vagus contains accelerator fibers. Here the accelerator fibers leave the spinal cord mainly through the third spinal nerve, then by the ramus communicans to the third sympathetic ganglion up the cervical sympathetic to join the ganglion on the trunk of the vagus and proceed with it to the heart. Hence the name vago-sympathetic nerve in the case of the frog. Irritation of the sympathetic in the frog before it joins the vagus causes the heart to beat quicker and it may not relax completely; the latent period is long and the force of the heart-beat is increased. The conduction of the impulses from the auricle to the ventricle is increased leading to an acceleration in the succession of the beats of the auricle and ventricle. After the stimulations end the heart slows. Because the heart-beats are augmented and accelerated at one time and at another independently of each other, it is supposed that there are two kinds of fibers, accelerators and augmentors. In the acceleration of the heart by irritation of the accelerators, both the diastole and systole are shortened, the volume of the heart diminishes, the systoles of the auricle and ventricle become more energetic. The increased rate of heart-beat persists a certain

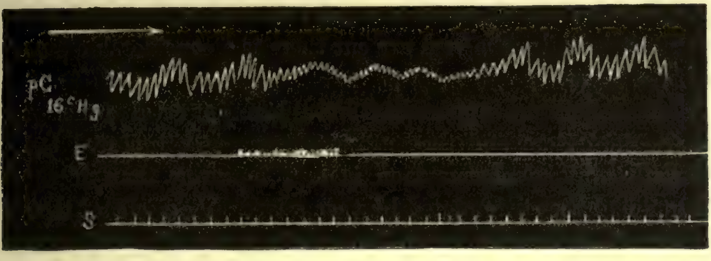

Fig. 85.—Acceleration of the Heart following an Irritation of an Efferent Branch of the First Thoracic Ganglion in a Curarized Dog. Action of Accelerator Nerve.

PC, Pressure in the carotid. E, Irritation of the nerve by an induction current. S, Time in seconds. The frequency of the pulse is more than doubled. (Gley.)

time after the irritation, then ensues a marked slowness. As to the blood-pressure, irritation of the accelerators as a rule causes no change, but instead of being elevated at times there is a fall. This lowering of pressure is a result of the heart not being filled during the frequent contractions. Hence the blood thrown out by the contractions of the ventricles into the arteries is less, and blood-pressure falls. It was formerly supposed that section of the accelerators did not change the rhythm of the heart, but Reid Hunt has shown that after extirpation of the inferior cervical ganglion and the first thoracic on the two sides, the vagi having been previously divided, the number of the heart-beats diminishes. Vagus inhibition could be more readily produced after the removal of the influence of the accelerators; hence the accelerator nerves, like the vagi, are always active in the normal heart. The accelerators produce their effects much better when the heart is beating moderately, for after the vagi are cut there is a considerable augmentation of the heart.

The accelerators apparently have less powerful functions, for when the inhibitors and they are simultaneously irritated the effect is *inhibition.* The phenomenon is less, however, than if the same inhibitors had been stimulated by themselves. Aside from their great and primary differences as to the effects produced, the accelerators differ in that they require a greater intensity of stimulus to produce any results; also in that a comparatively long latent period precedes every effect. In every respect the accelerators seem to be directly opposite to the inhibitors. They are the antagonists of the inhibitors.

Cardio-accelerator Reflexes.—H. E. Hering has shown by experiments upon rabbits that the increased heart-beat by muscular exercise does not ensue if the accelerator nerves have been divided, here a cardio-accelerator reflex exists. Aulo arrives at the previous conclusion of Johansson that the increased heart-beat after muscular exercise is neither due to chemical products of muscle activity nor to peripheral irritation, but to an associated stimulation of the cardio-accelerator center in the passage of a motor impulse.

D. R. Hooker, after section of the vagi and slowing of the heart by peripheral stimulation of one vagus, obtained acceleration of the rate of the heart by irritation of the sciatic, splanchnic and other nerves. All these facts indicate that the accelerator center stands in a reflex relation to the peripheral nerves.

Reid Hunt believes that it is rather the cardio-inhibitory centers which are inhibited than a reflex action exciting the cardio-accelerator centers.

Ludwig holds that the reduction of blood-pressure in the capillaries of the brain, but particularly those of the medulla, excites the accelerators. Oxygen is an accelerator. When the heart beats rapidly from any agreeable cause, or one feels "light at heart," the manifestation is due to the influence of the accelerator fibers on the heart.

Here a psychical action excites the center of the accelerator.

Thus, the heart is controlled by two nerves whose functions are diametrically opposite in character. They establish a system of "check" upon one another, each normally preventing extremes in the action of the other.

Influence of Drugs.—Because of the complicated action of various drugs upon the heart, many observers are led to believe that there are various internal mechanisms of the heart upon which these substances act. Besides acting upon the muscular tissue, some are found which exert influences upon the intracardiac nerves. The two drugs that are most familiar to the physiologist and with which he is most engaged in performing his experiments are *atropine* and *muscarine.* Their actions are both nervous. Thus, atropine paralyzes the inhibitory postganglionic fibers of the vagus, thereby giving the accelerators full sway, the consequence being augmentation of the heart's beats. On the other hand, muscarine stimulates permanently the inhibitory postganglionic fibers so that the heart-beats are slowed, or, if the dose be large enough, complete arrest of heart movement follows.

If a frog's heart be excised and placed in a suitable vessel and a few drops of a very dilute solution of muscarine be placed upon it, its beats will soon cease and it will continue quiescent as long as the muscarine remains upon it. When the muscarine is removed and atropine applied to the heart, its regular beats manifest themselves within a short time. Pilocarpine also stimulates the cardio-inhibitory postganglionic fibers and slows the heart. Atropine removes this and the heart beats faster.

Some drugs produce results by their effects upon the heart-muscle alone, either *stimulating* or *depressing* the same. Thus, the muscular contractions are rendered more forceful while the rate is uninfluenced by the action of strophanthus, etc. The muscular contractions are depressed by veratrum, aconite, etc.

In addition to drugs influencing the heart's action by effects upon its muscle and ganglionic nerve terminations, some exert an influence upon the vagus center in the medulla oblongata. Thus, aconite and adrenalin, by stimulating this center, produce a slowing of the heart-beats.

Digitalin on the frog's heart augments the duration and force of ventricular systole, slows diastole, and the arrest of the heart takes place in systole. This systolic stop of the heart ensues after section of the vagi or after the use of atropine, and is an action on the muscle. At other times the heart is slowed and arrest takes place in diastole, due to an action of digitalin on the cardio-inhibitory apparatus. This diastolic arrest does not ensue after the previous use of atropine. In the warm-blooded heart, we have a diminution of rate of the heart-beat, by digitalin and at the same time strengthening of the systolic force. Hence digitalis does the heart good by slowing the heart, increasing its rest in diastole and toning up its muscular structure.

Some heart-poisons in small doses diminish the heart's action and in large doses usually accelerate its movements; or the converse may be the truth with regard to the doses of other drugs.

NICOTINE.—The vagus fibers arborize around the nerve-cells of the crescent, the seat of Remak's ganglia in the frog's heart and from these ganglia new nerve-fibers run to the heart-muscle. The fibers running to arborize around Remak's ganglion or the crescent are called preganglionic fibers; those running from the ganglion to the heart-muscle are postganglionic.

Nicotine at first slows the heart because it has a stimulant action on the nerve terminals in Remak's ganglion and on the vagus center in the brain. But soon after the use of nicotine stimulation of the vagus is without inhibitory effect because nicotine paralyzes the terminals of the nerve or the receptive substance of the cells in the ganglion of Remak. Stimulation of the crescent after the use of nicotine stops the heart because the postganglionic fibers from the crescent are still active. These fibers are, however, poisoned by a dose of atropine. After a dose of nicotine, stimulation of the crescent often causes marked acceleration of the heart, because the accelerator fibers running in the vagus are stimulated, as they have no nerve-cells in their intracardiac course and go direct to their termination in the muscle.

Stannius Heart.—If in a frog's heart the Stannius ligature be applied around the heart at the junction of the sinus with the auricle, the auricle and ventricle stand still in diastole, and it is then called a Stannius heart.

Minimal Stimulus Causes Maximal Contraction.—If you excite once a minute the apex of a Stannius heart with an induced current of necessary intensity, commencing with currents too weak to cause a contraction, it will be found that finally the heart contracts. If the current is augmented, still, a contraction ensues of the same height as at first. The height of the contraction is independent of the intensity of the electric current. In other words, with very weak induction currents the heart either does not contract, or, if it contracts, does its best. With skeletal muscle, increasing the strength of the electrical stimulus increases the height of contraction.

As the cardiac contractions are always maximal, they make the heart independent of the strength of the stimulus and prevent strong stimuli from producing, in man, excessive contractions.

Staircase Contraction of Bowditch.—In a Stanniused heart where the ventricle is quiescent, single induction shocks of a constant strength, applied at intervals of five seconds, will produce contractions. It is found that for the first five beats the contractions become longer with each irritation. After that they remain about the same. This is called the staircase phenomena of cardiac muscle.

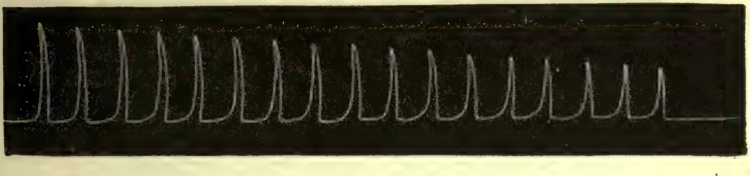

Fig. 86.—"Staircase" of Beats of a Stanniused Frog's Heart Excited by Maximal Induction Shocks at Intervals of Three Seconds. (WALLER.)

This is also seen in skeletal muscle Dr. F. S. Lee holds that this is due to fatigue-products.

Refractory Period of the Heart.—Marey observed that the irritability of the heart to weak electrical currents decreased during systole and increased during diastole. Thus, a weak induction current applied to a heart during systole does not call out a contraction, but only during diastole.

When a stimulus is thrown in at any point between the maximum of the systole and the beginning of the next contraction, it causes what is denominated an extra-contraction, which is followed by a longer pause than usual, the compensating pause.

The irritability being much lowered from the decomposition of energy-holding compounds is the cause of no contraction when the stimulus is thrown in during systole.

This compensatory pause is due to the dependence of the ventricular beat upon the beat of the auricle. When the auricle or ventricle is isolated the refractory period will not ensue. In a heart entire, the heart-beats start at the venous end of the auricle and is conducted to the ventricle.

If the ventricle is stimulated by an induction shock so as to give an extra beat out of the sequence, it will remain in diastole until the next impulse from the auricles shoots it off and thus picks up the regular sequence of heart-beat. The refractory period of the heart makes it irresponsive to all other stimuli and gives the heart a rest.

Nutrition of the Heart.—In the study of the nutrition of the heart, perfusion is usually employed. Ludwig and Wild, in 1846, were the first to perfuse an isolated heart of a warm-blooded animal. Newell Martin used the heart with the pulmonary circulation attached and perfused through the jugular. Langendorff perfused through the aorta of a completely isolated heart. The pressure of the fluid perfused closed the aortic valves, entered the coronary arteries and passed out through the open right auricle. By this method the heart beats for several hours. Langendorff also perfected an apparatus, which is usually employed for the perfusion of the mammalian heart. Von Cyon was the first to perfuse the frog's heart.

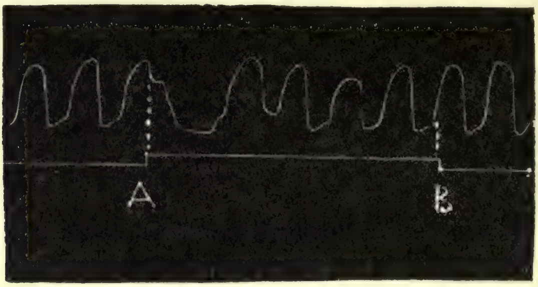

Fig. 87.—Refractory Period of Heart-muscle of Frog, with Compensatory Pause.

Shock applied at *A* is effective, causing an extra-contraction followed by a compensatory pause, at *B* stimulation is ineffective.

Rabbits' serum delayed the stopping of a beating heart, whilst hearts supplied with normal saline ceased to beat sooner than hearts left empty.

In the blood are found certain salts which are necessary to keep the frog's ventricle pulsating.

Merunowicz, in 1875, first discovered in Ludwig's laboratory that an aqueous extract of the ash of blood had the power to keep the frog's heart beating normally for hours.

Then Ringer, in 1883, discovered that his solution, known by his name, was capable of keeping the heart beating for hours. It consists of sodium chloride solution, 0.7 per cent.; calcium chloride, 0.00026 per cent.; solution of potassium chloride, 0.035 per cent. Oxygen is very beneficial when added to the Ringer solution.

Blood-corpuscles are not necessary for the contraction of the mammalian heart. Carbonic acid reduces the contractile force and rate of the heart-beat.

Locke found that, by adding a 1-per-cent. solution of dextrose to Ringer's fluid provided with oxygen, it kept the mammalian heart beating for hours. Hering, by an artificial circulation, restored the heart-beat for several hours in a man who had been dead eleven hours. Kuliabko, by Ringer's solution, restored the heart in animals who had been dead four days.

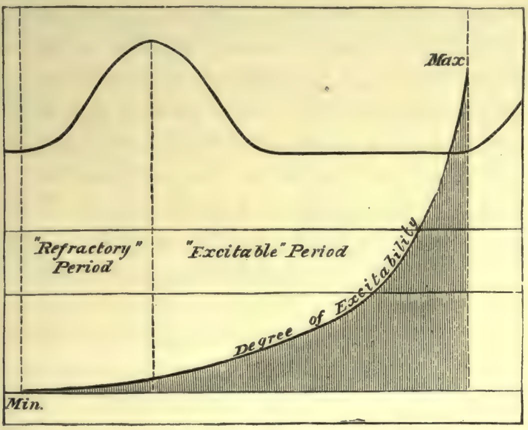

Fig. 88.—To Illustrate the Varying Excitability of the Frog's Heart at Different Periods of Systole and Diastole. (WALLER.)

The excitability is lowest during the first half of systole, greatest during the second half of diastole.

D'Halluin obtained in the heart of infants, by means of Locke's solution, feeble rhythmic contractions of the ventricles 24 hours after death. He also observed energetic contractions of the auricles 42 hours after the infant's death. In a dead monkey, Hering, with artificial circulation, found the vagus retained its inhibitory power for six hours after death, whilst the accelerator was active over fifty-three hours after death.

Porter has found that the mammalian heart beats best when supplied with blood from the same species of animals. Howell found that the ions of potassium salts are concerned mainly in the production of relaxation or diastole. The heart-muscle contains a considerable store of potassium. Loeb and Lingle believe that the ions of sodium have the most direct relation in the starting of the contractions of the heart. Ringer and Howell, however, hold it is rather the calcium salts which are most directly concerned in the production of the cardiac contraction. Howell believes the rôle of the calcium salts or calcium and sodium salts consists in replacing the potassium and converting a part of the store of stable material into an unstable, easily dissociable compound.

Howell's theory is as follows: The well-nourished heart contains a large supply of energy-yielding material which is in a stable form, so that it neither dissociates spontaneously nor can be made to do so by the action of external stimuli. It is possible that this stable, non-dissociable form consists of a compound between it and the potassium or potassium salts, and that herein lies the functional importance of the large amount of potassium contained in the tissue. This compound reacts with the calcium or with the calcium and sodium salts and a portion of the potassium is replaced and a compound is formed which is unstable. At the end of the diastolic period this compound reaches a condition of such instability that it dissociates spontaneously, giving rise to the chain of events that culminates in the normal systole.

Howell infers from experiments, that within certain limits an increase and a decrease of potassium salts when perfused in the terrapin's heart increases and decreases the sensitiveness of the heart to inhibition by the vagus. Vagus inhibition is accompanied by an output of potassium, according to Howell.

Busquet and Pachon have shown that the perfusion of isotonic solutions of sodium through the frog's heart *in situ,* causes the vagus and the sinus to lose their power of inhibition. If, however, one part of calcium chloride is added to 50,000 parts of the isotonic solution of sodium, then the inhibitory power of the vagus returns. The function of calcium here is specific in maintaining the activity of the cardio-inhibitory apparatus. Auer and Meltzer have shown that a weak infusion of calcium restores the irritability of the vagus, which has been greatly reduced by a magnesium salt. Larger doses of calcium abolished the irritability of the normal vagus.

It seems that calcium is more concerned with inhibition than potassium. Howell and Duke found, when they perfused the mammalian heart for hours, and, at the same time stimulated the accelerators for a long period, that the perfused liquid showed no variation in its content of potassium or calcium.

Langendorff and Engelmann believe that some specific substance is formed in metabolism of the cardiac muscles, a so-called specific inner stimulus is the origin of the heart-beat. The inorganic salts are only accessory in the production of this stimulus.

Effect of Temperature.—The heart of the frog or the excised heart of the mammal is very sensitive to temperature changes. Heat increases the beat and cold slows it, and the variations in the heart-beat vary directly with the changes of temperature. The heart-beat of a cat at 104 degrees F. is four times more rapid than at 59 degrees F. As the temperature of the heart falls the height of the contraction increases up to a certain point, and at the same time the shortening becomes slower and more prolonged. The rate and force of the heart in cold-blooded animals reaches its optimum at about 86 degrees F. Above this the beats decrease in force and also in rate, becoming irregular. Newell Martin determined the effect of heat on the heart of warm-blooded animals. He found that the highest temperature at which the heart will beat is about 112 degrees F. It ceases to beat at a temperature of 64 degrees F. In fever we have a rapid heart-beat, due to the elevation of temperature.

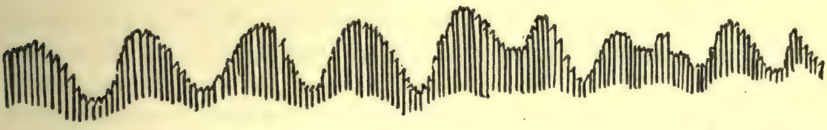

Fig. 89.—Variations in Tonus of Auricle of Terrapin's Heart. (FANO.)

Tonus of the Heart.—The volume of the heart and the capacity of its cavities are kept always somewhat reduced as a result of a slight tonus in its fibers.

Heart-muscle, like other muscle, is never entirely relaxed or completely contracted. Fano has shown that the auricles of the turtle undergo a series of changes in tonus in the muscles, which represent the ordinary contractions of the heart. The venous end of the heart has the greatest tonus. These changes in tonicity are nearly always a result of pressure upon the auriculo-ventricular groove. The ventricle very seldom has alterations of tonus. Fano believes these changes in tonus are myogenic. He thinks these alterations in tonus are due to a substance different from that which causes the usual contractions of the heart.

Bottazzi holds that the tonus is due to sarcoplasm. The curves he believes should be considered spontaneous isometric curves of sarcoplasm. Muscarin stimulates the changes in tonus; atropin and nicotin completely paralyze them. The tone of a heart is not constant, and it opposes dilatation of the heart from pressure on the inside of its cavities during their relaxation.

Lessening in tone is one of the most frequent occurrences in heart disease, and when tone is decreased, conductivity and excitability are increased; and this may explain some of the most frequent cases of irregularity of the cardiac organ.

Digitalin applied to the heart-muscle of the terrapin, shortens it, raises the line of tonicity of the auricles and diminishes the rate and the variations in tonicity. In man digitalis has the power to increase the tone of cardiac muscle, and prevent dilatation of the heart. The poisons of diphtheria and influenza lower heart-tone.

THE ARTERIES.

All vessels *leaving* the heart are *arteries.* From it proceed the aorta and pulmonary artery, the former from the left, the latter from the right ventricle. All of the branches of the arteries continue to divide to form smaller arteries, these in turn become arterioles, which are followed by capillaries (hair-like vessels). To cause as little friction as possible the branches are almost uniformly given off at an acute angle. The total area of the cross-sections of the branches is usually greater than the sectional area of the original trunk from which the branches sprung. As the distance from the source is increased the area supplied by the branches is increased also, giving the general impression of a cone in its contour; its base is outlined by the capillaries, its apex being represented by the point from which the branch springs from the parent trunk.

The pulmonary artery arises from the right ventricle in front of the origin of the aorta under whose arch it very shortly passes, then to divide into two main branches, one for each lung. Within the lung-substance they divide and subdivide very rapidly to form numerous capillaries, in order that the blood may become thoroughly oxidized. The arteries, (unlike veins) are usually found empty and dilated after death.

Arterial Structure.—The walls of the arteries are composed of three coats: an internal one of endothelial nature, the *tunica intima;* a middle coat of muscular fibers, *tunica media;* and an external, cellular coat, *tunica adventitia.*

TUNICA INTIMA.—The tunica intima of the arteries is the thinnest coat, the most transparent and elastic. These properties permit the caliber of the artery to be enlarged without any great danger of rupturing its walls.

TUNICA MEDIA.—It is composed of two varieties of tissue: (1) muscular and (2) elastic.

The unstriped muscular fibers run in a circular direction around the vessels. In the large arteries there is a predominance of elastic tissue; in the arterioles there is no elastic, but muscular tissue. The contractility of the arteries depends upon the muscular tissue. Where there is an excess of elastic tissue there is very little muscular tissue in the blood-vessel, and where the elastic tissue is at a minimum there is a maximum of muscular tissue.

TUNICA ADVENTITIA.—This coat is composed of bundles of connective tissue with some elastic tissue.

VASA VASORUM.—Like every other tissue, the wall of the vessels needs nutritive supplies. This is supplied by small capillaries which run only in the tunica adventitia of the blood-vessel. To these vessels has been given the name of *vasa vasorum.*

VEINS.

Like the arteries, veins are branching tubes; but they are larger, more numerous, and as a consequence have more capacity to hold blood. Veins have their beginnings in the capillary vessels, which by gradually uniting form the small veins. These small veins unite to form larger ones, the venæ cavæ, which empty into the right auricle. The veins have about three times the capacity of the arteries. The veins consist of a superficial and deep set, the former not associated with the arteries and being subcutaneous, the deep set usually running along the side of the artery and hence called venæ comites. Anastomoses between the veins of large size are more frequent than in the corresponding arteries. The veins, like the arteries, have an external, a middle, and an internal coat. The coats of the veins are much thinner than the coats of the arteries, and when divided the veins collapse, while the arteries, divided, stand open. The walls of the veins are inelastic.

Valves.—The chief feature of the veins are the valves, which are so arranged as to prevent the blood from flowing backward. The valves ordinarily are in pairs opposite each other and are formed of crescent-shaped doublings of the lining membrane of the veins, with some interposed fibro-elastic tissue. The valves are directed toward the heart. If a vein is compressed the blood is driven back and presses the valves inward and closes the vein. The pulmonary veins contain no valves, and the same may be said for the superior and inferior venæ cavæ, the portal vein, and most of those of the head and neck. The veins of the lower extremities contain more valves than the corresponding vessels of the upper extremity. In certain organs channels are seen lined with an extension of the internal coat of the vein, which are called venous sinuses, as in the dura mater and uterus. Vasa vasorum are also distributed to the veins. In the coats of both arteries and veins are lymph-spaces.

The nerve-supply to the arteries is liberal, to the veins much less so. The supply is derived chiefly from the sympathetic system, with a few filaments from the cerebro-spinal system.

THE CAPILLARIES.

The smallest arteries suddenly divide into an extremely fine network of hair-like tubes, the capillaries. These furnish the connecting link between arteries and the beginnings of veins. They serve as the intermediate agent in all structures, between the arteries and the veins.

Each capillary tube is from $^1/_{2000}$ to $^1/_{3000}$ inch in diameter, while it averages $^1/_{30}$ inch in length.

Capillaries are composed of the same kind of endothelial cells as the intima of the arteries; in fact, the capillaries seem to be the prolongations of the lining of the arteries. Their walls are made up of a single layer of lance-shaped endothelial cells. In the wall of the capillary between the cells we find the cement-substance which permits the blood-corpuscles to penetrate it in diapadesis. These little vessels penetrate the spaces between the cells of the tissues in such a fine network that many of the cells are in contact with several vessels. So closely arranged are they that the point of a very fine needle cannot enter the skin without injuring some of them.

The total capacity of the capillaries is about three hundred times that of the arteries.

THE CIRCULATION OF THE BLOOD.

The physicians and naturalists of antiquity, even at the epoch when they were permitted to get enlightenment from anatomy, remained in ignorance of the *circulatory movement* of the blood. The circulatory apparatus is not one of those the mere inspection of which could reveal its function; in fact, when viewed in a cadaver illusions are very apt to rise. In it the arteries are empty and show a gaping cavity when incised, so that they were thought to contain air or some *subtle spirit,* the latter taking its origin in the ventricles of the brain to reach, in some unaccountable manner, the circulatory system. To them the name artery was given, since the veins alone were believed to be the true blood-vessels. Such was the opinion entertained by men who lived in the fourth and fifth centuries before the Christian era.

In the second century of our era Galen discovered, by means of vivisections, that the arteries contain blood. He even admitted that the arteries communicated with the veins. But, as if to pay his debt to error, he professed that the two hearts are in communication with one another through numerous apertures which riddle the septum that separates the two. For nearly fourteen centuries the opinions of Galen had inviolate authority, when it was finally ascertained by Vesalius that the separating septum was *not* perforated. It was Michael Servetus who, in a theological work, clearly pointed out the passage of the blood from the right heart to the left through the *pulmonary blood-vessels.* His system was true, but not based upon experiment, since he knew nothing of the heart's force and valves.

It was in 1628 that William Harvey published his immortal discovery of the circulation of the blood. True, a great deal had been suspected and there abounded a perfect chaos of confused and scattered facts. He established by numerous and admirably interpreted experiments his doctrine of the two circulations: *great* and *small.*

To-day it would be superfluous to recall all of the arguments which Harvey had to make use of to prop up that doctrine. Therefore there will be stated here only some of his experimental proofs, the interpretation of which appears easy to us in the light of our present knowledge.

When an artery is opened, said Harvey, the blood issues in unequal jerks, alternately weaker and stronger. The stronger coincides with *diastole* of the *artery* and consequently with ventricular *systole.* Also, if an artery of a living animal be cut across, the blood continues to gush by jerks from that end of the vessel still in communication with the heart, whereas it soon ceases to flow from that severed end which is more remote from the central organ.

When the arm is bound, as for bleeding, the veins swell up below the ligature to become knotty on a level with their valves. If force be attempted to press the blood away from the heart, the knots become more marked; on the contrary, if the blood be pressed toward the heart, it passes freely. From this Harvey deduced that the direction of the venous blood is from the periphery to the heart.

When an artery is obstructed, the blood accumulates between the heart and the obstacle; on the contrary, the accumulation in the case of a vein is between the obstructed point and the general capillaries. In the arteries, therefore, the blood flows *from* the heart to the extremities; in the veins, from the extremities *toward* the heart.

If an artery be completely severed and the animal's blood be permitted to flow, all of its blood will eventually pass through the opening. Would this occur if there were not a continual passage of the blood from the heart to the arteries, then to the veins, and finally to the heart again; that is to say, a true circulation?

This great physiologist also observed that if poison be injected at but a single point there will follow a general constitutional disturbance, explained only by the movement of this vital fluid throughout the entire body.

To be able to ascertain by vision the direct passage of the blood from the arteries into the veins was not allowed Harvey. It was left to Malpighi, who, in 1661, while examining the lung and mesentery of a frog with the aid of a microscope, was able to note the circulation of the blood in the capillary blood-vessels. The spectacle of capillary circulation within the web of a frog's foot or tail of a tadpole is within the reach of every student. Harvey was denied this from lack of lenses powerful enough to demonstrate it.

Now that the general plan of the circulation has been noted, attention is naturally turned toward the principles governing the flow of the blood. The mechanical act of impulsion can be readily imitated by physical apparatus, but physics do not account for a certain part of the body receiving blood, now more, now less, abundantly; becoming congested or pale, warm or cold; and at the same time the impetus remaining perceptibly the same.

By employing a simple piece of apparatus, designed by E. H. Weber, the main, simple, physical phenomena of the circulation may be simulated. To imitate the Harveian circuit, take a piece of small intestine, sufficiently long, and join the two ends so that there is formed a closed and circular conduit. A part of this elastic conduit is limited by two valves which open according to the direction it is desired that the current of liquid should go. The arrangement of the valves is such that all backward flow is prevented. On filling the apparatus with water by means of a funnel, it is ready for operation. When any portion of this elastic conduit is squeezed the liquid immediately beneath the point of pressure attempts to escape. This it can do only in one direction (because of the valves), thereby producing a forward motion of the liquid. With each compression there follows a corresponding wave, so that if the compressions be numerous enough the liquid will move round and round within the conduit. This represents only very imperfectly the circulation of the blood; in the living apparatus the impulse of the heart is not at the end of the venous system.

From the operation of even so simple a piece of apparatus, it cannot but be noticed that the circulation depends upon a *difference* of *tension*. Liquids always take the direction of the pressure. The obstruction offered to the blood in the presence of the capillaries has a tendency to increase arterial tension at the expense of venous pressure. The narrower and more difficult the capillaries to be traversed are, the greater is arterial pressure, or *vice versa*.. The prime cause of difference of pressure is ventricular contraction, aided, however, by elasticity of vessels.

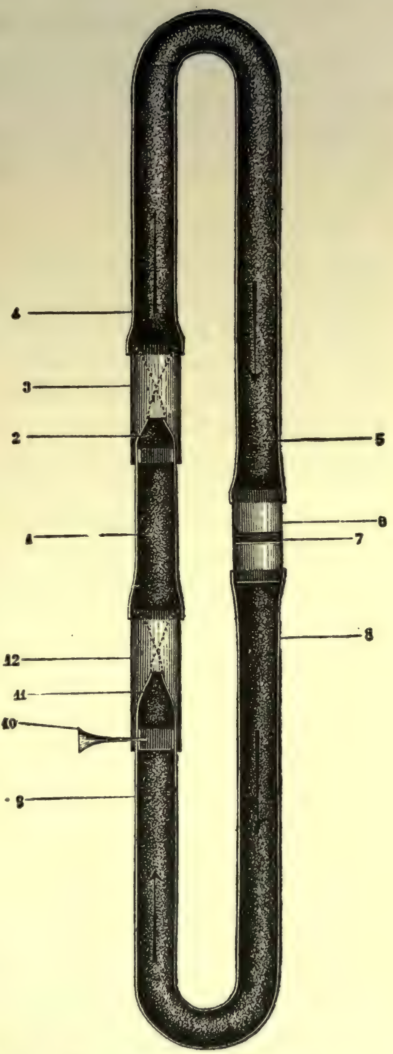

Fig. 90.—Weber's Schema.

4-5 and 8-9 are two pieces of intestine of the same size. 6, A piece of glass tubing. 11 and 2, Two wooden tubes. 1, A short piece of intestine. 3, 12, Valves which open only in one direction. 1 represents the ventricle. 10, A funnel to let water enter the schema. 4-5, The arterial system. 8-9, The venous system. 7, A sponge representing the capillaries. 3, The semilunar valve. 12, The auriculo-ventricular valve.

CIRCULATION IN THE BLOOD-VESSELS.

This field of physiology presents problems of a physical nature, in that the flow of the liquid, blood, is through tubes. But it must be remembered that the tubes employed in the circulation are living, more or less elastic ones, and that physical laws are correspondingly altered.

The analogy between the nervous system and the telegraphic system is a very striking one, and is much used by physiologists and others. Even more forceful is the analogy between the circulatory system and the system of water-supply of a town or city, except that there is no return of the latter's fluid to the starting-place. The water starts upon its flow from the elevated reservoir to pass through large mains at first and is distributed through branches that become smaller and smaller as they subdivide on their way to different houses. Likewise, the blood starts from the centrally located, pumping heart, passes through large trunks at first, to be distributed through branches that become smaller and smaller as they subdivide on their way to different tissues. In short, the physical laws of the circulation are the modified physical laws of the flow of liquids through tubes. From this it will be readily deduced that a competent knowledge of the laws of circulation must be preceded by some knowledge of physical laws. These will be referred to from time to time in the treatment of the present subject:

The flow of liquid is caused by a difference of pressure between the different parts of a body of liquid. The attraction of the earth (gravitation) provides a continuous pressure which will produce a flow of liquid along channels or through tubes, provided the source be elevated and the outlet low.

The circulation through the heart-vessels is also caused by a difference in pressure due to the primary propelling force of the heart-action. That is, the pressure in it exceeds that of the arteries; the latter's pressure, kept high by the heart's force and peripheral resistance, is greater than that in the capillaries. Though that exerted in the capillaries is small, it is yet in excess of that existing in the veins. The lowest pressure is found in the blood about to enter the heart after having first made its circuit through the body-tissues. The direction of the flow of any liquid is always from the higher pressure toward the lower; therefore the flow of blood within the body is from the heart around through the body back to the heart again; that is, it *circulates.*

ELASTICITY OF THE ARTERIES.

It is known that the blood is sent out by the heart in an intermittent manner, each contraction of the ventricle pushing a mass, as the stroke of the piston of a force-pump would do. If, however, the movement of the blood in the capillaries is observed with a microscope it is ascertained that in the normal state it is perfectly continuous. The movement of blood has been transformed in its course from the heart to the extremities. This transformation of the movement is due to the elasticity of the arteries. Hydraulics had ascertained this remarkable effect of elasticity in fire engines, for example; the water from the machine is rendered less jerky by running liquid under a bell filled with air; the elastic force of the gas thus compressed transforms the brief and intermittent impulsion of the stroke to a continuous stream.

Intermittent Afflux Apparatus.—Marey has experimentally demonstrated that, in the case of *intermittent afflux* of liquid in a conduit of a given caliber, the elasticity of that conduit increases the quantity of the liquid that can penetrate there under a given pressure.

Suppose a force-pump, from which runs a tube furnished with a stop-cock; a tube which bifurcates at a point to be continued by two conduits of the same caliber. One of these is made with elastic walls *(C)*, the other with rigid walls *(B)*. A valve placed in the elastic tube prevents the liquid from flowing back from the tube, but offers no obstacle to its direct current. Two lips of the same caliber are fitted to the ends of the two tubes.

When the stop-cock is opened and the outflow is permitted to establish itself in a continuous manner, both the rigid and elastic tubes pour out the same quantity of liquid. If, on the contrary, the stop-cock be opened and shut alternately so as to produce an intermittent access of the liquid, the outflow is greater through the elastic tube than through the rigid tube.

The blood-circulation being of the intermittent afflux order, the arterial elasticity is favorable to the entrance of the blood thrown off by the heart.

As the arteries are elastic the volume of blood ejected by the ventricle is accommodated by the temporary enlargement of the larger arteries and is driven forward according to E. H. Weber, by the force stored in their walls, so that only a part of the column must be moved at the systole. The heart is relieved of considerable work by the elasticity of the arteries. The ventricle is able to send out a quantity of blood with much less expenditure of force.

The circulation in the arteries is under the dependence of two very important properties of these vessels: *elasticity* and *contractility*. The nature of the movement of the blood, has, therefore, been transformed in its course from the heart to the extremities. It is now known that this transformation is due in the main to the *elasticity of the arteries.*

Each new entrance of the blood into the arterial system must necessarily be accompanied with a dilatation of the whole vascular tree. As soon as the three ounces of blood ejected from the left ventricle has penetrated into the aorta, as it flows through the capillary system, there results a contraction of the whole arterial system until the moment when a new output of blood arrives.

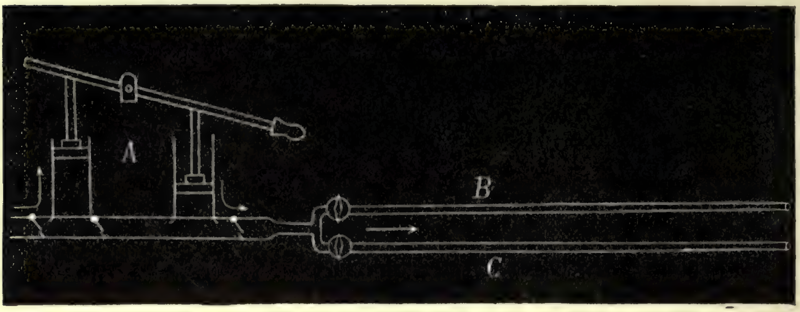

Fig. 91.—Marey's Intermittent Afflux Apparatus. (Lahousse.)

A, Force-pump. *B*, Tube with rigid walls. *C*, Tube with elastic walls.

It has been ascertained experimentally that the arterial vessels are much more elastic in the direction of their axis than in their transverse diameter. It is in the former direction then that increased capacity of the arteries will especially occur. When the trunks of the arteries are of considerable extent the elongation may become apparent to the naked eye, as in the temporal artery, while there does not seem to exist any increase in the transverse direction of the same vessel.

According to Weber, the principal rôle of arterial elasticity is to establish, between the arterial and venous tensions, a *difference* which is indispensable to the movement of the liquid within the circulatory apparatus. In addition, the uses of vascular elasticity may be said to be twofold: On the one hand, it saves the heart a considerable display of force; on the other, it furnishes the small vessels with a continuous and constant flow of blood.

Next in importance to the elasticity of the vessels is the power of *contractility,* by which the caliber of a vessel is changed and the supply of blood to any part or organ of the body altered. This property co-operates with elasticity, so that the lumen of any given vessel is proportionate to the pressure exerted. Were it otherwise, at some times the pressure would be too small, at other times too great, for the quantity of inclosed blood. The power of contractility is very prominent in the small arteries.

THE PULSE.

At each ventricular systole the ventricular contents are forced into the arterial system, but, because of the high peripheral tension, they are unable to pass along as a unit. In fact, the artery just beyond the heart becomes distended because of this influx, but by virtue of its elasticity it strives to regain its normal caliber, thereby giving to the blood *some* motion. The main impetus of the blood is given by the succeeding systoles, until the smaller arteries are reached when the vascular elasticity asserts itself more, and so helps along the blood-stream. By this means the blood is caused to circulate. If the vessels were inelastic, just as much blood would be forced out of the veins into the heart again as the heart at each beat injects into the arteries. Though the blood in the elastic vessels of the body cannot move freely as in the inelastic tubes, yet there is propagated at each ventricular systole a *wave* which runs to the periphery of the body. This wave is a *transmission* of a wave of pressure *throughout the length of the arterial tree.* The pulse-pressure is the difference between the systolic- and diastolic-pressures. To this wave has been given the name *pulse.* The impulsion moves very swiftly without the liquid itself participating in that swiftness.

The pulse of the radial and the impulse of the heart do not take place at the same time. The radial pulse is perceived a short interval after the cardiac impulse. This interval is termed the pulse delay, for between the heart-impulse and the appearance of the radial pulse it is seventeen hundredths of a second. The radial pulse never succeeds the second sound of the heart, but is about midway in time between the first and second sounds. The pulse is not synchronous throughout the vascular system, the carotid pulse is felt before the radial.

The time comprised between the beginning of the contraction of the ventricle and the moment of the elevation of the sigmoid valves, sometimes called the pre-sphygmic interval, 0.04-0.07 second, makes the first element in the retardation of the pulse-wave in the beginning of a cardiac pulsation. The second element in retarding the pulse is the rate of the spreading of the pulse-wave in the arterial system. The rate of the spreading of the pulse-wave is about 30 feet per second, which is very different from the rapidity of the current of blood, which is about 12 inches per second. The rapidity of the ventricular wave varies as the force of the heart, and inversely is proportional to the resistance of the orifices and to the arterial tensions. When a systole of the heart is revealed by a beating of the radial artery, there is not, at that moment, under one's finger a single drop of the blood thrown off by the last systole. The pulse may be compared to a wave produced by throwing a stone into the pond.

The three factors concerned in the production of the pulse are: (1) the action of the heart, (2) the elasticity of the large vessels, and (3) the resistance of the smaller arteries and the capillaries.

The pulse is really a shock, perceptible to the touch at each increase of the arterial tension, and produced by successive affluxes of the blood which the heart throws off.

In order to perceive that shock, the vessel must be pressed by the finger so as to make it lose its cylindrical form at that point. By reason of the dilatation of the vessel, the finger is raised at that point. That is, one perceives the pulse. As there may exist various changes in the arterial tension, so there may be various types of pulse. Variations are, for the most part, pathological, and so may be considered to be outside of the domain of physiology.

When the physician feels the patient's pulse he gains valuable information as to the condition of the heart and vessels. The examination of the characters of the pulse is usually confined to that portion of the radial artery which lies in the wrist. Here the artery is covered only by skin and subcutaneous tissue, while in addition the shaft of the radius forms a bony support against which the artery may be compressed by the fingers. From the pulse are noted the following points: *Force, rate* and *fullness.*

While such *main* features of the pulse were able to be depicted by experienced finger-tips, it was felt that there was still very much that the pulse would tell could it be translated.

Everyone has seen the movements produced in a limb by reason of the pulsations of the popliteal artery, when one leg is kept crossed over the knee of the other. The leg in this position represents typically a lever of the third class.

One observer conceived the idea from this phenomenon that the pulse can be very accurately studied by using a very light lever so attached that it will oscillate at each heart-beat. By virtue of a large arm to the lever the amplitude of the oscillations is so exaggerated that they can be readily seen by the naked eye and their movements graphically depicted upon smoked papers. The instrument capable of determining the various elements of the pulse and so depicting them that they can be studied at leisure has received the name *sphygmograph.*

The Sphygmograph.—The name whereby this instrument is known is derived from two Greek words which mean "to write the pulse." It does write, for to-day graphic records of the various features of the pulse are obtained by its use.

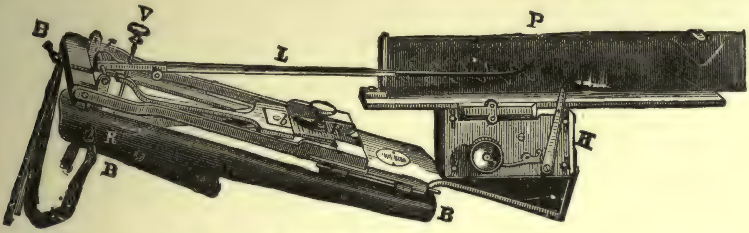

Fig. 92.—Marey's Sphygmograph. (YEO.)

The parts *B*, *B*, *B* are fastened to the wrist by the straps *B*, *B*. The remaining part of the instrument rests on the forearm. The end of the screw, *V*, rests on the spring *R*, the button of which lies on the radial artery. Any movement of the button at *R* is communicated to *V*, which moves the lever, *L*, up and down. When in position the blackened slip of glass is made to move evenly by the clockwork, *H*, so that it records the movements of the lever.

The essential feature of this instrument is its system of compound levers whereby the initial motion is multiplied about fifty times. The foot of these levers rests upon the skin over the artery whose tracing is to be taken. Motion is transmitted from it to the other end of the levers, where is inserted a recording needle.

The second feature of the apparatus is the recording instrument, composed of clock-work, which revolves a pair of small cylinders between which is moved a ribbon of blackened paper. The recording-needle's point rests upon this paper, correctly depicting there the various features of the pulse.

In addition, each instrument is provided with an apparatus by adjustment of which the pressure is so regulated that the best record may be obtained. The graphic record, or pulse-tracing, is known as the sphygmogram.

A sphygmogram is a graphic representation of the variations of pressure inside an artery.

The main features of the sphygmographic record are an abrupt ascent with a descent that is more gradual and wavy, representing the rise and fall in pressure due to ventricular systole and diastole. The wavy appearance of the downstroke is due to the elastic recoil being more constant and of longer duration than the ventricular systole. The sudden upstroke represents very forcibly the sudden influx of blood into the aorta during systole, while the more gradual downstroke represents the slower fall of arterial pressure during diastole.

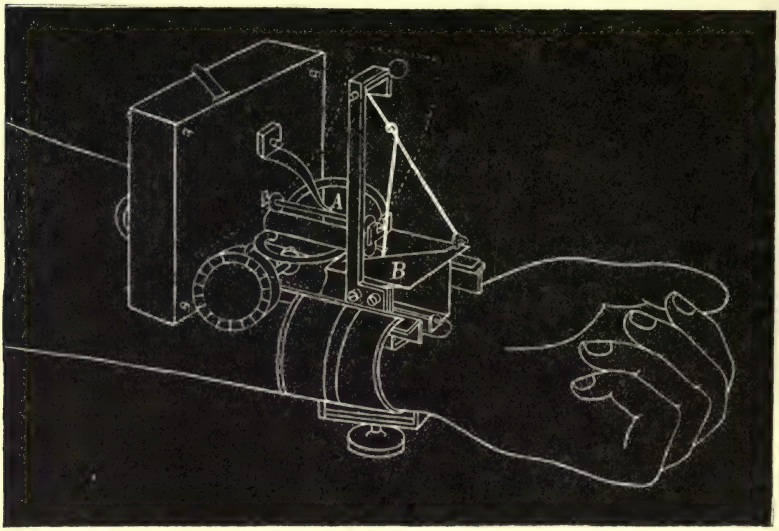

Fig. 93.—Dudgeon's Sphygmograph. (Lahousse.)

The line of ascent represents the dilatation of the artery by ventricular systole when the semilunar valves are forced open and the contents are projected into the artery. The top of the primary wave is pointed normally; so has received the term *apex*.

As a rule, the ascent of the pulse-curve is nearly vertical. When a series of closely-placed elastic vibrations occur in the upper part of the line of ascent so that the apex appears dentate and forms an angle with the line of ascent, then the sphygmogram becomes anacrotic.

The anacrotic pulse is seen in Bright's disease, where the peripheral resistance is high, and in stenosis of aorta.

The more gradual downstroke is interrupted by *two completely distinct elevations* of secondary waves, though in the lowest part of the descent there may be several minor inequalities. The more distinct of the two occurs at about the middle portion of the line of descent. It represents the *dicrotic wave;* from its mode of origin it is sometimes called the "recoil wave." Between the apex and the dicrotic wave occurs the *predicrotic,* or *tidal wave,* while below the dicrotic wave occurs the *postdicrotic wave* or waves, since there are very frequently several.

The line of ascent and the predicrotic wave are caused by systole, while the dicrotic wave takes place during diastole. The postdicrotic waves are a result of vascular tension.

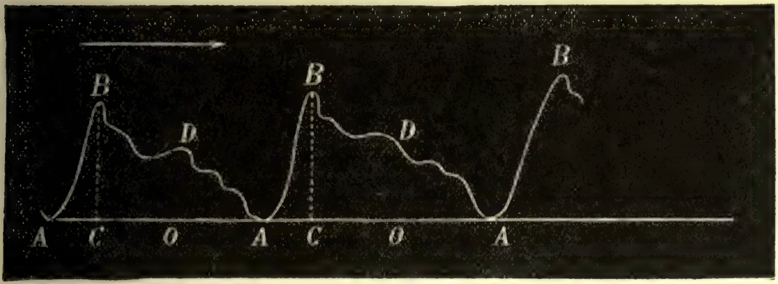

Fig. 94.—Sphygmogram Magnified. (LAHOUSSE.)

A, *B*, Correspond to the dilatation. *B*, *D*, *A*, Correspond to contraction of artery. *A*, *C*, *O*, *A*, Measures the total duration of pulse. *B*, *C*, represents the height of the pulse. *D*, Is the dicrotic pulse.

Origin of the Dicrotic Wave.—At one time this wave was believed to have its origin in the periphery, but is now known to be caused as follows: By ventricular systole there is projected into the full aorta a mass of blood so that a positive wave is propagated from the heart toward the periphery, where it *becomes extinguished* among the smallest arterioles and capillaries. At the closure of the semilunar valves, the arteries from having just been distended begin to contract or recoil upon the contained blood, with the result that this newly exerted pressure sets it into motion in two directions: toward the heart and toward the periphery. In the latter direction the passage is free until the capillaries are reached; toward the heart the still closed semilunar valves are met with such force that there results a recoil. This develops into a new positive wave, which gives the dicrotic wave in the sphygmogram. Atheroma diminishes the dicrotic wave, because the arterial wall is more rigid.

MacKenzie explains the dicrotic wave as follows: At the moment the aortic pressure rises above the ventricular the valves close and are supported by the hard, contracted ventricular walls. The withdrawal of the support by the sudden relaxation of these walls will tend to produce a negative pressure wave in the arterial system. This negative wave is stopped by the sudden stretching of the aortic valves, which, losing their firm support, have now themselves to bear the resistance of the arterial pressure. This sudden check of the negative wave starts a second positive wave which is propagated through the arterial system as the dicrotic wave. A low arterial tension favors dicrotism, which is, however, normal in all persons.

The dicrotic notch indicates the beginning of diastole and the closure of the aortic valves.

A dicrotic wave at or near the base line of the curve shows a low arterial pressure, since the artery easily collapses after its systolic distension.

THE CAPILLARY CIRCULATION.

From anatomy it was learned that, with but very few exceptions, blood passes into a network of very thin-walled and hair-like vessels, the capillaries; this network communicates with the finest radicles of the veins, so that it forms a connecting-link between the veins and arteries. Anatomically, the capillaries are distinguished from the arterioles by the absence of circularly arranged muscular fibers which the arterioles possess and by whose contraction, under vasomotor influence, their lumina are diminished. However, the caliber of the capillaries is subject to change also by reason of passive blood-pressure exerted upon their endothelial cells. The real cause of the blood-pressure in the capillaries is *ventricular systole;* but this is *modified* by the *caliber* of the *arterioles.*

It is from the interior of these hair-like vessels that fluid enters into contact with organic tissues for their nourishment and growth. The tissues in turn unload themselves of those effete and deleterious matters which represent the products of catabolic processes.

From these reciprocal actions between the tissues and the blood there result in the latter profound modifications after it has passed the capillary system. The blood now presents the destructive characters of venous blood.

Placed between the last ramifications of the arteries and the first radicles of the veins, the capillary system is blended with these two orders of vessels without the intervention of any transitional medium.

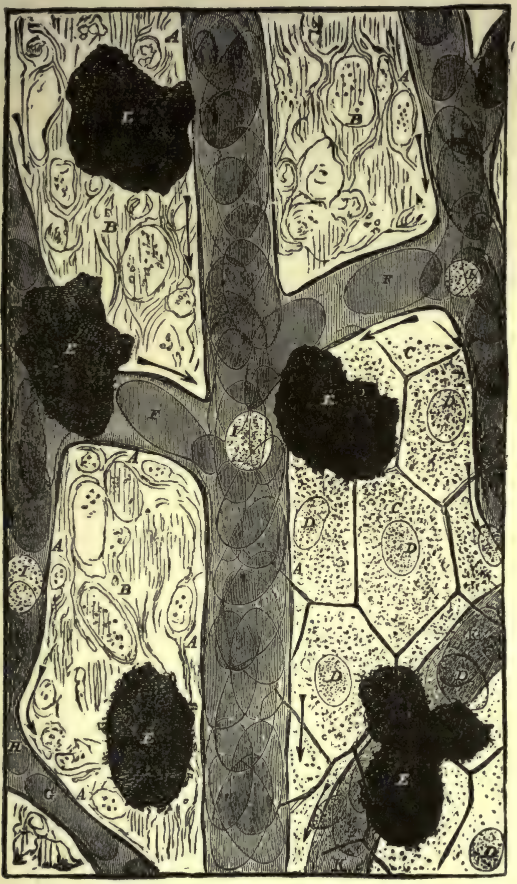

Fig. 95.—Frog's Web, Highly Magnified. (Yeo, *after Huxley*.)

A, Wall of capillary. *B*, Tissue lying between the capillaries. *C*, Epithelial cells of the skin. *D*, Nuclei of epithelial cells. *E*, Pigment-cells, contracted. *F*, Red blood-corpuscles. *G*, *H*, Red corpuscles squeezing their way through a narrow capillary, showing their elasticity. *I*, White corpuscles.

The limits assigned to their system by anatomy are purely fictitious. Physiology would be greatly embarrassed if it had to determine the precise point where the vessels are no longer only organs of transport for the blood, but permit an exchange between the blood and tissues through their walls. The anatomist places the *length of the capillary* at *one-thirtieth of an inch.*

As previously stated, the capillary wall is formed entirely of a simple layer of endothelial cells. They are flat, lance-shaped cells joined edge to edge and represent the continuation of the intima of the arteries. The outlines of the cells with their lines of junction may be beautifully demonstrated by nitrate of silver staining. In the capillaries stained by silver there is here and there to be seen between the cells an increase in the amount of the intercellular substance. The white blood-corpuscles when migrating from the blood-vessels pass between the endothelial cells.

Microscopical Examination.—When a thin and vascular membrane belonging to a *living* animal is placed in the field of the microscope, the admirable spectacle observed for the first time in 1661, by Malpighi, is seen: *the blood is circulating in the capillary vessels.* For this examination, frogs present several parts which are suitable: the interdigital membrane, mesentery, tongue, bladder and lungs.

Differences in volume of the capillaries have much influence upon the movement of the blood in their interior. In the widest capillaries a rapid current takes place, and the corpuscles are carried along with a velocity which does not permit distinguishing their form clearly. In the smallest vessels, on the contrary, the corpuscles progress slowly. In fact, the slowness of the current and disappearance of the pulse are the chief characteristics of the capillary current. For, normally, the flow through the capillaries is in a *steady, constant stream.*

In the very smallest vessels the corpuscles are often at some little distance from one another. They seem to advance with difficulty and to rub against the walls of the vessels. According to many observers, the corpuscles are sometimes obliged to bend out of shape in order to traverse these narrow channels.

At other times, in the midst of the intricacy of the vessels and of the various directions of their current, two capillaries are seen to join a third. Corpuscles coming along the two vessels alternately pass into the single capillary, which receives them one by one, and through which they pass in single file. Elsewhere may be seen a pile of corpuscles, distinct from each other, and all of which progress with the same swiftness. All hasten and slacken their pace at the same time. At other points a complete immobility is seen in consequence of some temporary obstruction or of the contrary direction of the current; then all at once the corpuscles start off again.

Except in the very smallest capillaries, it is noticed that the red corpuscles always move in the axis of the current, while on either side of this thread of moving cells there is noticed a transparent layer of liquor sanguinis which is almost perfectly still or possesses only slight motion. This layer, "Poiseuille's still space," where it is plainly discernible, occupies about one-fifth of the space on each side of the axial current, which occupies the remaining three-fifths of the lumen of the vessel.

Within the smaller blood-vessels the red corpuscles occupy the middle of the stream, where, in single file, they glide along with comparative rapidity; in larger vessels two or three may flow along abreast. Along the outer edge of the central thread of red blood-corpuscles move the white ones, many even getting into the space of Poiseuille. The motion of the white corpuscles is one of rolling, particularly when they are in the clear space next the vessel-wall or in direct contact with the latter, since they are sticky by nature. The contact of the rapidly moving axis current also assists in giving to the white corpuscles their rolling motion. Their motion is so slow at times that they adhere to the vessel-wall.

It has been demonstrated by physical experiments that particles of least specific gravity (white corpuscles) in all capillaries are pressed toward the wall, while those of greater specific gravity (red corpuscles) remain in the middle of the stream.

One of the characteristics of the capillary circulation is the *disappearance of the pulse.* Ordinarily this has been accomplished by the resistance which is offered to the current on its way to the periphery. When, for any reason, the arterioles are greatly *relaxed,* and there exists at the same time high blood-pressure, so much blood flows into the capillaries from the lessened resistance to its current that a distinct *pulse* passes along the capillaries to the veins. This pulse is characteristic of aortic insufficiency or in cases of atheroma of the arteries. In the latter condition the vessels become calcified and rigid and so behave physically as inelastic tubes.

Cause of Movement of Blood.—*The force of the heart transformed into arterial tension* is the real cause of the movement of the blood in the capillaries. This is not the only influence, for gravity can exert influences that are either favorable or opposed to the current of the blood.

Swiftness of Blood in the Capillary System.—Since very many conditions are capable of modifying the velocity of the blood-current, it is a very difficult task to ascertain the numerical valuation of that swiftness. If the time a corpuscle takes to traverse a course of a known length be measured under the microscope, a fairly accurate estimate can be made. Due allowances must be made for exaggerations from the magnifying power of the microscope.

It is thus estimated that the corpuscles traverse *one inch per minute* through the capillaries in man.

BLOOD-PRESSURE—ARTERIAL, VENOUS AND CAPILLARY TENSION.

The blood-pressure within any vessel may be looked upon as the *stress* upon the inclosed liquid at the point of observation. Pressure of the blood has been placed before the student's attention quite frequently during the discussion of the circulation of this vital fluid. Its consideration has been but superficial, however, up to this point.

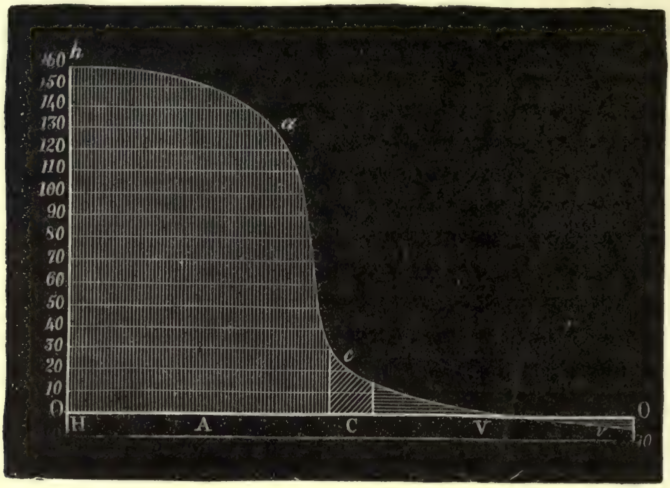

Fig. 96.—Showing the Relative Heights of Blood-pressure in Different Blood-vessels. (YEO.)

***H*, Heart. *A*, Arteries. *a*, Arterioles. *c*, Capillaries. *V*, Small veins. *v*, Large veins. *H-V*, Being the zero-line, the pressure is indicated by the elevations of the curve. The numbers on the left give the pressure in millimeters of mercury.**

The blood-pressure depends upon three factors, the peripheral resistance, the force of the heart and the quantity of the blood.

If the quantity of the blood ejected by the heart decreases for a time, other things being equal, the pressure falls. The acceleration of the heart-beat will cause the blood-pressure to depend upon the reciprocal relation between the increase of frequency of the pulse and the volume of the blood ejected. When both vagi are divided or the accelerators are stimulated and the heart-beat is accelerated, it may or may not throw out more blood in a given time. If more blood is expelled by the heart, the diameter of the arterioles remaining the same, the blood-pressure increases. A quicker heart-beat does not always indicate a greater systolic force, and thus does not necessarily mean a greater amount of blood ejected. When the arterial pressure is high the pressure in the left ventricle reflexly stimulates the vagus-center, slows the heart, lessens the output of blood, and thus counteracts the high blood-pressure. Low blood-pressure increases the rate of the heart-beat. The pressure in the circulatory system varies with these factors as variants. Pressure will be greater with greater heart-force or with greater peripheral resistance. The direction of flow is always from a point of higher to one of lower pressure.

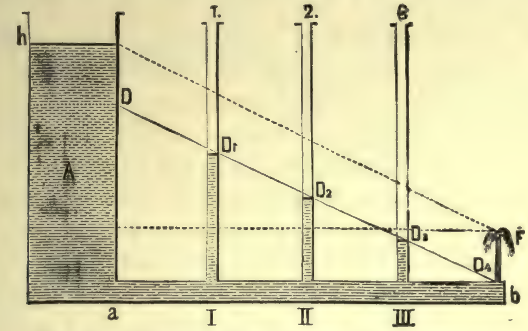

Fig. 97.—Variations in Pressure. (Landois.)

A, Cylindrical tube filled with water. *a-b*, Outflow tube, along which are placed at intervals the vertical tubes, 1, 2, and 3, to estimate pressure.

The further the blood proceeds from that center of circulatory motive power, the heart, the less becomes the pressure exerted by it. It must be greatest, therefore, in the arteries emanating from the heart and least in those veins emptying into the right heart. The decrease is rather gradual along the vascular course until the venæ cavæ are reached; at their point of entrance into the heart the blood-pressure is frequently found to be negative; that is, below atmospheric pressure.

Thus, the arterioles will be found to possess a pressure that is peculiar to them, as do the capillaries and veins in their turn. The intensity of the pressure will depend upon the resistances to be overcome and the *vis a tergo* that is impelling the blood-current. Thus the arterial pressure depends upon the relation existing between the blood thrown out by the ventricles and the quantity that can pass through the capillaries in the same time.

Science has possessed for a long time the means of knowing what is, in inelastic tubes, which are the seat of the flow, the force of afflux for each point of their length, and what, also, is the quantity of that force which has been consumed by the resistances.

In order that the student may gain some knowledge of the causes that produce variations in the pressure as well as the means of measuring and recording it, attention will be turned briefly to the physical world to note the simplest possible apparatus that can convey even a vague idea of this property of the blood's circulation.

Suppose a reservoir full of liquid to a certain level, and from the bottom of which runs a pipe of uniform caliber. The tubes which branch from this main pipe are of equal caliber and are placed at equal distances from one another. The upright tubes have received the name of *manometers.* If, now, there be a flow of the liquid it will be because of a difference of pressure at the reservoir and outlet. During this flow the liquid in the various manometers will contain columns of the liquid whose tops would be in contact with a straight line drawn from the superior surface of the contents of the reservoir to the point of egress. This slanting line is known as the *pressure-slope.* The manometer nearest the reservoir contains the highest column of liquid, the next one a column of less height, etc., the lowest being attained in the upright tube farthest from the heart or reservoir.

The height to which the liquid rises in a manometer sensibly indicates the intensity of the force of afflux at that point. And, as it decreases from the orifice of entry to that of exit, it must be concluded therefrom that the force of the flow of the liquid decreases of itself. It has been demonstrated in physics that the resistances which liquids meet with in ducts of a uniform caliber are *proportional* to the *length of the latter.* It follows, therefore, that, when the flow is established in the tube the more distant from the ingress a point of that tube is, the more the liquid which passes through it will have lost its initial force in consequence of resistances.

The more narrow the caliber of the tube, the greater is the resistance to the liquid. Up to the time of Rev. Stephen Hales, an English vicar, the methods of noting blood-pressure were crude in the extreme. It was known that the blood exerted considerable pressure upon the arterial walls, for, when they were punctured, an intermittent jet of blood arose to a considerable height, the latter depending upon the proximity of the wound to the heart. When a vein was wounded the blood was noticed to exude with much less force, and it was continuous, not intermittent.

Hales was the first to make any improvement upon this rough movement, which he did by inserting a brass pipe one-sixth of an inch in diameter, in lieu of a cannula, into the femoral artery of a horse about three inches from the abdomen. The brass pipe in the artery was connected by means of another brass pipe to a glass tube whose height was nine feet, its bore nearly the same diameter as the brass pipe, and placed vertically. The first blood-pressure experiment is, perhaps, best depicted in the words of Hales himself. He says: "In December, 1733, I caused a mare to be tied down alive on her back. She was fourteen hands high, and she had a fistula on her withers and was neither very lean nor yet very lusty. Having laid open the left

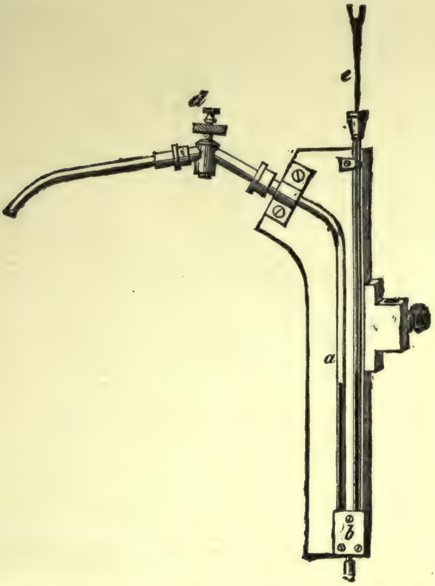

Fig. 98.—Manometer of Mercury for Measuring and Registering Blood-pressure. (Yeo.)

a, Proximal glass tube. *b*, Union of the two glass tubes of the manometer. *d*, Stop-cock through which the sodium carbonate can be introduced between the blood and the mercury of the manometer. *e*, The rod floating on the mercury carries the writing-point.

crural artery about three inches from her belly, I inserted into it a brass pipe whose bore was one-sixth of an inch in diameter. To that, by means of another brass pipe, which was fitly adapted to it, I fixed a glass tube of nearly the same diameter and which was nine feet in length. Then, untying the ligature on the artery, the blood rose in the tube eight feet three inches perpendicular above the level of the left ventricle of the heart. When the blood was at its full height, it would rise and fall at and after each pulse two, three, or four inches. Sometimes it would fall twelve or fourteen inches, and demonstrate at that point the same up-and-down vibrations, at and after each pulse, as it had when it was at its full height. After forty or fifty pulses it would rise to the former height again.

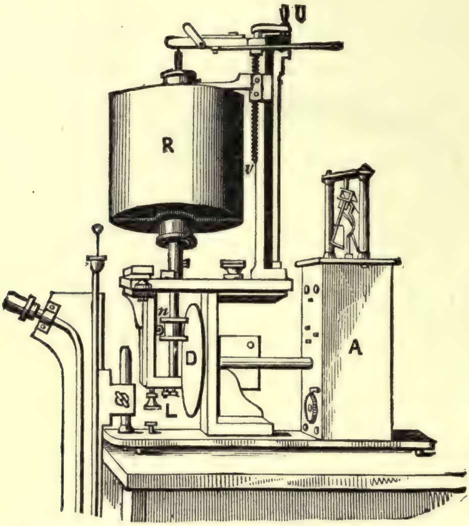

Fig. 99.—Ludwig's Kymograph. (Yeo.)

R, Rotating drum blackened, which is moved by the clockwork inclosed in A by means of the disc, D, pressing on the wheel, n. The cylinder may be elevated or depressed by the screw, v, which is actuated by the handle, U.

"Later I took away the glass tube and let the blood from the artery mount up into the open air, when the greatest height of its jet was not above two feet."

Though the first real truths concerning blood-pressure were thus gained, nevertheless the method was crude and cumbersome in that the blood would soon clot and an eight-foot column of blood was not easily watched in its fluctuations.

Poiseuille, in 1828, introduced into physiological experimentation a manometer with a column of mercury. This instrument is more convenient to handle, and with it all of the scientific world is acquainted to-day.

The manometer with its column of mercury has undergone still further modifications. Thus, Magendie has employed, under the name of *hæmometer,* an instrument composed of a mercury reservoir. Upon this the blood-pressure is exerted, and it communicates with a tube in which the metal rises. The height of the level of the mercury in that single tube expresses the intensity of the pressure.

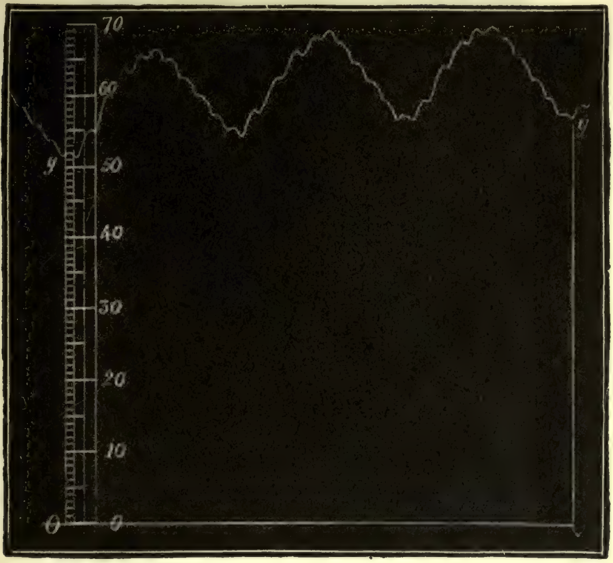

Fig. 100.—Blood-pressure Curve Recorded by the Mercurial Manometer. (YEO.)

c-x, Zero-line. *y-y*, Curve with large respiratory waves and small waves of heart impulse. A scale is given to show height of pressure in millimeters of mercury.

By use of the mercury as a substance against which the blood may expend its force, the inconvenience of handling the great column of blood is overcome.

One objection to the mercury is that columns of it, in their oscillations, take on acquired momentum, which makes them pass beyond the points which exactly express the *maximum* and the *minimum* of blood-pressure.

When such instruments are used, care must always be taken to prevent the coagulation of the blood by introducing an alkaline solution into the points of the apparatus where the blood must penetrate. The liquid most commonly used is a saturated solution of sodium carbonate.

In 1847 the study of *arterial tension* entered a new phase, thanks to the use made by C. Ludwig of the *apparatuses with continuous indications* to measure the variations which that tension undergoes under the influence of many conditions. The instrument that he used is known as the *kymograph,* or "wave-writer." In brief, it consists of a U-shaped manometer, in the open limb of which a light float is placed upon the surface of the mercury. A writing-style is placed transversely upon the free end of the float, which inscribes its movements, representing the oscillations of the mercury, upon a cylinder which revolves at a uniform rate by reason of clock-work. There is recorded not only the *height,* but its pulsatile and respiratory oscillations.

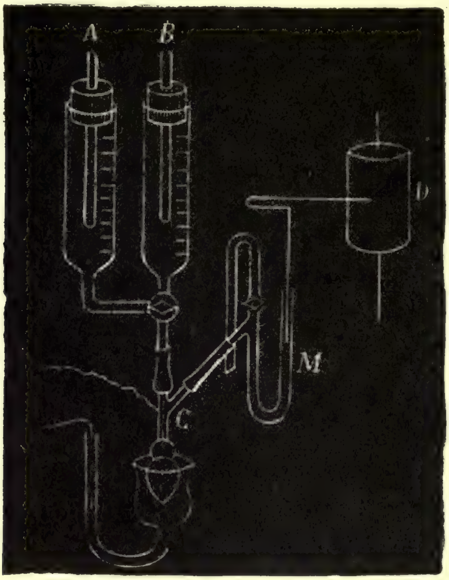

Fig. 101.—Cardiac Manometer. (LAHOUSSE.)

A and B, Two burettes of glass able to communicate with the bifurcated cannula, C, by the aid of a stop-cock with three openings. M, Small mercury manometer. D, Smoked drum.

In looking at a blood-pressure tracing we find that the *large undulations* are produced by respiratory movements. Usually the ascent is caused by inspiration, the descent by expiration. Each of the *small* waves corresponds to heart-action, the slight ascent to systole, the slight descent to diastole. In studying a tracing it must be remembered that the real blood-pressure is really twice what is recorded, since the needle moves through a space that represents the difference of level between the mercury of the two tubes.

Dawson has called attention to the fact that when we speak of blood-pressure we should state whether systolic or diastolic, for the systolic may exceed the diastolic pressure by as much as 100 per cent. of the latter. These two may vary independently of each other. By taking the average height of systolic pressure and obtaining the average mean pressure, Dawson has found that the mean pressure is nearer the diastolic level than the systolic level. He states the pulse-pressure is the difference between the diastolic and systolic pressure. For instance, in the right brachial artery of the dog the systolic pressure was 156, its mean 118, the diastolic pressure was 101, then the pulse-pressure would be 55. The pulse-pressure is an index of the variation in pressure in any artery caused by the heart-beat.

Each contraction of the heart stretches the artery by a sudden increment of pressure equal in the right brachial to 55 millimeters of mercury. The pulse-pressure becomes less as we approach the periphery of the vascular system, as the oscillations between systolic and diastolic pressure become less. Dawson found the mean pressure to be practically constant throughout the large arteries, but when the small arteries are reached there is a conspicuous decrease. The diastolic pressure is also constant in the larger arteries. The diastolic end pressure in the femoral is slightly and invariably lower than that of the carotid.

Blood-pressure in Man.

Since it is impossible to ascertain blood-pressure in man as it is practiced in animals, numerous instruments have been invented that can be used and applied to superficial arteries without dissection of the tissues. These pieces of apparatus have been variously termed *sphygmometers, sphygomanometers, etc.*

Sphygmomanometer.—The *Riva-Rocci sphygmomanometer* consists of a canvas band bound close about the arm. Within the canvas band is a rubber bag which communicates with a mercury manometer and with the rubber bulb which produces the pressure. When the canvas band is in place, the rubber bulb is rhythmically compressed and air forced into the rubber bag around the arm. This inflated bag exerts a pressure upon the arm and upon the brachial artery. The pressure is increased until the radial pulse disappears at the wrist. The moment the radial pulse disappears, the mercurial column indicates the systolic pressure in the artery of the arm.

The instrument of Riva-Rocci gives the systolic pressure. Mosso, however, invented an instrument which gives the diastolic pressure. The principle involved in Mosso's instrument is a registration of the pulsations of the artery under different pressures, and finding out under what pressure maximal pulsations are obtained. This pressure should be equal to the diastolic pressure inside the artery. Howell and Brush have proved this on the exposed artery of a dog.

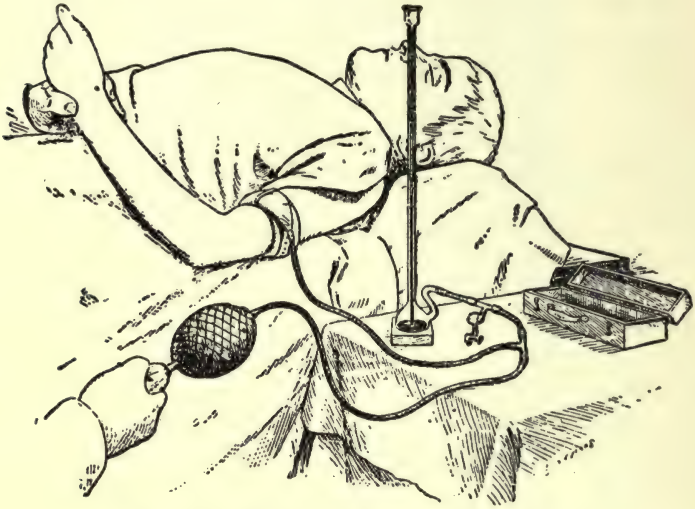

Fig. 102.—Riva-Rocci Sphygmomanometer.

The Sphygmomanometer of Mosso.—In this instrument the two middle fingers of each hand are placed in rubber capsules inside metallic tubes, and the pressure regulated to obtain the greatest excursion of the mercury manometer. In this instrument water-pressure is used outside an artery, and increased so as to exactly balance the internal pressure; then the oscillation of the arterial walls will be greatest when they are free to move. There are several sphygmomanometers in this country, and the best is that of Dr. Erlanger.

The maximum systolic and minimum diastolic pressure can be determined by the Erlanger apparatus. To measure the maximum systolic pressure the arm is compressed by the air-cuff until no pulse

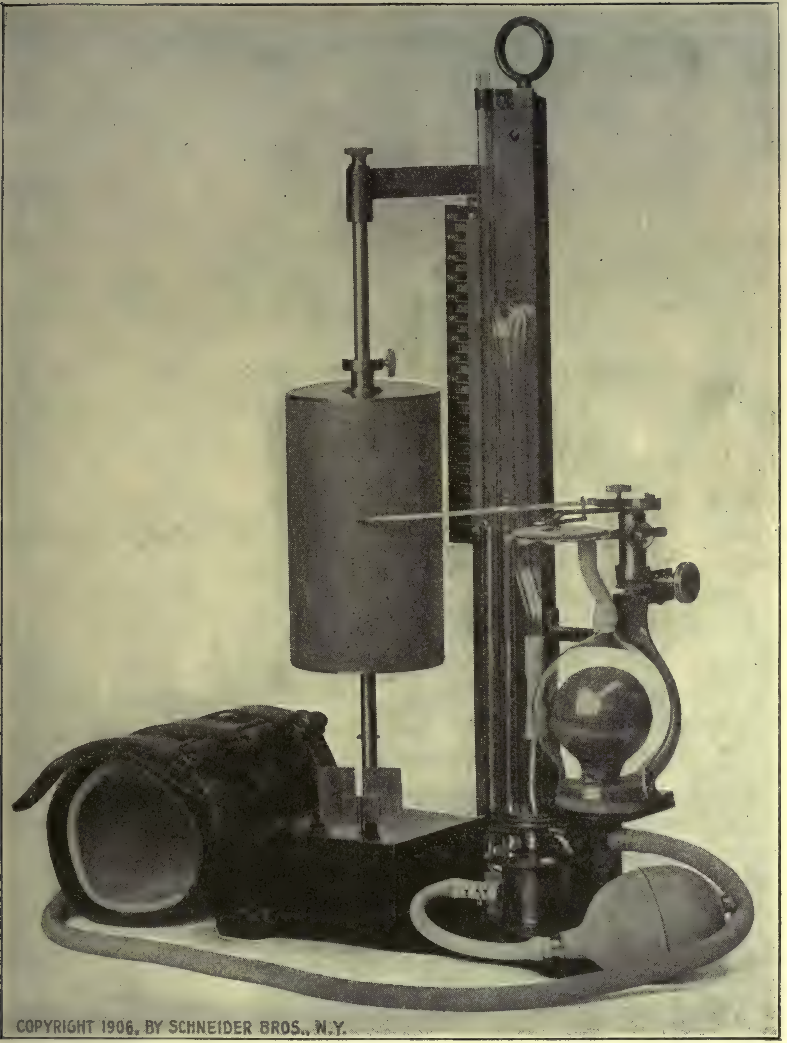
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Fig. 102*a*.—Erlanger's apparatus for Determination of the Blood-pressure in Man.

The apparatus is provided with a pneumatic cuff, which consists of an inside rubber bag and an outside leather band. The whole cuff can be buckled around the arm above the elbow. The air cavity within the rubber bag of the cuff communicates through a thick-walled rubber tube and a four-way connection, $_2{=}\overset{3}{\underset{1}{\dashv}}{=}$ with the three other essential parts of the apparatus, namely: (1) *downward*, with the valved bulb, by means of which air can be forced into the cuff and can thus be made to compress the arm; (2) *to the left*, with the mercury manometer, from which the amount of pressure applied to the arm can be read directly in *mm* of *Hg;* and (3) *upward*, with the distensible bag inside the glass chamber. This bag, last mentioned, responds to fluctuations of pressure inside the rubber bag of the arm, which are due to vibrations of the arterial wall, and the tambour at the top records such vibrations on the drum. (TIGERSTEDT.)

can be felt in the artery. The tambour at this time exhibits vibrations due to the arterial pulse; but if the air-pressure in the cuff on the arm be gradually lessened by means of an escape valve, these vibrations become longer, and when this state of affairs ensues it shows the pressure which the pulse-wave can just overcome, and is the maximum systolic pressure.

If the pressure be decreased still more the vibrations of the tambour lever become larger until a point is reached at which they begin to decrease. The pressure where the greatest fluctuations of the arteries ensue causes the most extensive movements of the lever, and is the minimum diastolic pressure.

The majority of clinical sphygmomanometers give only the systolic pressure, and this pressure is the one usually meant when we speak of a patient's blood-pressure in the clinic. But there is also a diastolic pressure which depends upon the degree of contraction of the peripheral arterioles. Systolic pressure gives us a knowledge of the force of the left ventricle, whilst diastolic pressure teaches us the tone of the arteries.

It must be remembered that fallacies exist in the use of such an instrument. For the matter is only too evident that there will be recorded compression of the venæ comites of the artery, the skin and surrounding tissues. Further, it is impossible to tell the exact moment when the distal pulse is rendered imperceptible.

Erlanger obtained in the brachial artery an average pressure of 110 millimeters during systole and 65 during diastole. He also found that a heavy meal was followed by an increased output of blood by the heart, as revealed by an increase in pulse-pressure.

In the case of healthy, young adults, the pressure in the brachial artery ranges between 110 and 130 millimeters of mercury. Pressure attains its maximum with the individual in the erect position; its minimum when he assumes the horizontal.

Blood-pressure must always be sufficient to cause a steady flow of blood through the capillaries, and this must be at least 50 millimeters of mercury. The blood-pressure which keeps up a head of pressure above this to meet the varying calls of the organs for more blood is about 70 millimeters.

The blood-pressure remains at its normal height when the blood-vessels receive an excess of fluid, or when the vessels contain less than normal amount. When the excess of fluid arrives in the vessels it remains in the central veins and in the liver, which becomes very hard. This excess of fluid soon passes out of the vessels into the tissues.

One-half of the transfused blood is transuded into the tissues at the end of the first day. This fluid in the tissue is carried off by the glands, especially the kidneys, and by the intestinal mucous membrane. Where the vessels are underfilled with blood, as by blood-letting, the blood-vessels contract, the secretions diminish and the water of the lymph goes back into the blood-vessels.

Extremes of Pressure.—The *highest* pressure is registered in the aorta. While traversing the arteries the fall in pressure is very gradual. Immediately upon its passing from the arterioles into the capillaries and there meeting great resistance, the pressure fall is very marked.

The blood-pressure continues to fall in the capillaries and veins until the cardiac portion of venæ cavæ are reached, when the *lowest* pressure is registered. As stated elsewhere, this last pressure may be negative.

The causes of alteration in blood-pressure of arteries, according to Brunton, are as follows:—

It may be raised:

1. By the heart beating more quickly.

2. By the heart beating more vigorously and sending more blood into the aorta at each beat.

3. By contraction of the arterioles retaining the blood in the arterial system.

It may be depressed:

1. By the heart beating more slowly.

2. By the heart beating less vigorously and completely and sending less blood into the aorta at each beat.

3. By dilatation of the arterioles, allowing the blood to flow more quickly into the veins.

4. By deficient supply of blood to the left ventricle, as from contraction of the pulmonary vessels or obstruction to the passage of blood through them, or from stagnation of the blood in the large veins, as in shock.

The blood-pressure in the pulmonary artery is about one-third to one-seventh that of the aorta.

Pathological Action.—Blood-pressure in disease generally increases instead of decreases. Sleep and muscular rest lower blood-pressure; mental and muscular exercise, meals, excitement and cold increase it. We have apoplexies mainly in winter because of the cold, which also is aided by increase of venous tension, caused by any sudden strain, as in defecation.

In surgical shock and in collapse we have a low pressure, blood pools in the most dependent parts or in the splanchnic area. The splanchnic arterioles regulate the variations of systemic blood-pressure, and they have been called the "resistance box" of the circulation. There is an antagonistic play between the splanchnic system and cutaneous circulation. When one contracts the other dilates, which explains the cold feet or chilliness during digestion. Stolnikow has shown that the liver also acts as a blood reservoir for the systemic circulation, whilst the lungs act as a reservoir for the pulmonary circulation. Hence we have pooling of the blood in the vessels of the liver and lungs in a weak heart. In the lax abdominal muscles of women or in weak vasomotor centers, the blood can pool in the splanchnic area when standing for a long time and cause fainting. In neurasthenia the vasomotor system loses local control and we have throbbings and flashes of heat.

In unconsciousness produced by chloroform the blood-pressure falls about 30 millimeters. Alcohol depresses arterial tension. Faivre, by actual measurement in man during the amputation of a leg, found the mean pressure 115 millimeters.

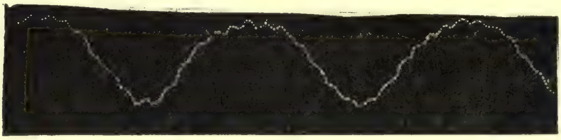

Fig. 103.—Traube-Hering Curves. (Fredericque.)

Respiratory Undulations.—In studying a graphic record of the heart's action one is struck with the almost rhythmical rise and fall of the general tracing. There is thus depicted the condition of arterial pressure conjointly with the graphic representation of the heartbeats. They are produced by the respiratory movements, and hence have been termed *respiratory undulations.*

Traube-Hering Curves.—These are curves which are higher than the regular respiratory undulations, but less frequent. They are due to alterations in the condition of the small arteries, superinduced by the waxing and waning at regular intervals of the excitability of the main vasomotor center.

Vagus and Blood-pressure.—When the blood-pressure rises in an animal the usual sequence is for the pulse-rate to be diminished by virtue of stimulation to the cardio-inhibitory center of the vagus. A fall in the blood-pressure is followed by an increase in the rate of heart-action. If the pneumogastrics are divided the pulse-frequency increases, and as a result the arterial tension rises. If the vagi are irritated the pulse-rate falls and as a sequence the arterial tension diminishes.

Eyster and Hooker found that the slowing of the heart in animals with intact vagi from increase of arterial pressure is due to two facts which normally act together: (1) a direct effect of the increased blood-pressure upon the cardio-inhibitory center; (2) a stimulation of the cardio-inhibitory center through the afferent nerves, resulting in a reflex slowing of the heart. The afferent path of the reflex has its origin, at least to a great extent, in the thoracic aorta. The reflex slowing of the heart from increase of arterial pressure persists after section of the accelerator and depressors. The afferent path of this reflex is in part of fibers contained in the vagus.

Lecrenier has confirmed these observations.

The reciprocal power of the pulse and blood-pressure to regulate each other depends on normal pneumogastrics.

Pathological.—In cases of granular or contracted kidney, sclerosis of the arteries, and where digitalis is used in heart affections, the blood-pressure is raised. Injected ergotin, by causing contraction of the arterioles, also raises pressure, while morphine lowers the same. The blood-pressure falls in the ending of fevers.

Capillary Blood-pressure.—Von Kries has estimated the blood-pressure in the capillaries of the ear to be about 22 millimeters of mercury.

The pressure is greatest in the lower extremities, hence we have an increased transudation from them or even rupture.

Water or blood extravasated in the sub-conjunctival tissues are often the result of the high blood-pressure in chronic Bright's disease. Capillary pressure is regulated more by the blood-pressure in the veins than in the arteries. Gravity increases pressure in the capillaries.

Pathological Action.—In a feeble heart with retrograde pressure in the veins increased, the slow capillary flow of blood receives an excess of carbonic acid and cyanosis of the skin ensues.

Venous Blood-pressure.—Since the pressure is so low (even negative in places) within this system, a saline solution is usually substituted in the manometer for mercury. The kymographic tracing taken near the heart shows the characteristic large and small waves, with this difference, however, that the respiratory rise accompanies *expiration*.

Venous blood-pressure is *increased* by all conditions which tend to *decrease the difference* of pressure between the arterial system and itself. The reverse will produce diminution in its tension. General plethora increases it; anæmia diminishes it. As one proceeds from the heart there is found the development of a positive pressure.

The blood-pressure in the veins near the heart is negative because of the aspiration exercised by the thorax. Thus, in the superior vena cava of the dog it is — 3. millimeters of mercury, in the right brachial + 3.9 millimeters of mercury, in the left femoral + 5.4, and in the left saphena + 7.4. As these facts show, the venous pressure is higher the more distant the vein is from the heart.

In order that the blood stream shall continue in a uniform manner, the quantity of blood received by the heart from the veins in the same period of time must be equal to that ejected by the heart into the arteries.

Veno-motor Nerves.—The veins are contractile. If you irritate the peripheral end of a splanchnic there will be a narrowing of the portal vein and its branches within the liver. Irritation of the peripheral end of a sciatic causes a contraction of the veins of the posterior extremity. Hence the veins, like the arteries, are in a state of tonus similar to that which exists in the arteries and under control of the central nervous system.

Venous Pulse.—This pulse in the jugular is a visible sign of a circulation in the veins. The pulse is due to the auricular systole, which produces not a reflux but a temporary arrest in the flow of venous blood. The venous pulse seen in disease differs from the preceding as regards cause. It is due to insufficiency of the tricuspid valve. Here the reflux of blood, when the ventricle contracts, produces the venous pulse.

In the figure is represented a schema of a jugular pulse tracing with a tracing of cardiac pulsation. The first wave, the most important, forms the venous pulse, and is due to contraction of the auricle. It is not caused by a reflux, but by a temporary stoppage of the flow of blood, a positive wave running backward in the veins. The second wave according to Mackenzie is caused by the carotid beating near by the vein. Bard, however, holds that the second wave is due to the rapid tightening and doming of the auriculo-ventricular valves.

The third wave, according to Mackenzie is produced by the sudden checking of the venous flow at the period of great distention of the auricles. This wave occurs toward the end of the systole of the ventricle. Bard believes the third wave is caused by the base of the heart being pulled toward the apex during ventricular systole, thus dilating the cavity of the auricle and producing an aspiration on the venous flow. The arrest of this aspiration when the auricle is full of blood at the end of the ventricular systole stops the flow of blood in the veins and thus a wave is produced.

Fredericque and Delchef believe the second wave is not the beating of the carotid as held by Mackenzie, but is due to closure of the tricuspid valve.

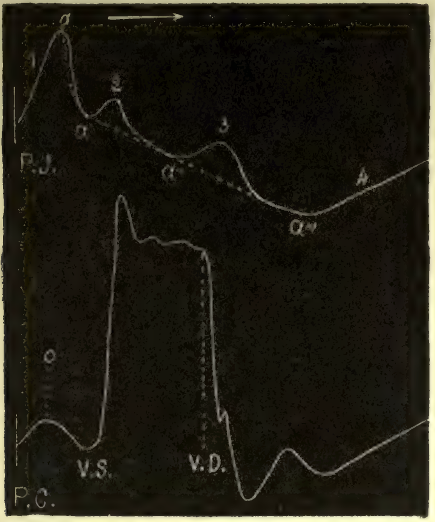

Fig. 103 *a*.—Schema of the Normal Jugular Pulse (*P. J.*). (François-Franck.)

1, Curve of ascent due to auricular systole. *a*, Curve of descent which commences at the diastole of the auricle and continues during the ventricular diastole, *VD*, notwithstanding the two small elevations 2 and 3, one of which is produced by the sudden tension of the ventricular muscle at the moment of systole, *VS*, with the elevation of the tricuspid valve. The wave 2 marks the beginning of ventricular systole, wave 3 the end of ventricular systole. 4, Swelling of the vein due to the gradual filling of the venous system. *PC*, Cardiac pulsation.

Morrow of Montreal, makes six waves in the venous pulse tracing which may be named either from their supposed cause or from their time relations to the cardiac cycle, as follows:—

1. The auricular or presystolic wave.
2. The ventricular or systolic wave.
3. The auricular or systolic collapse.
4. The first onflow or prediastolic wave.

5. The ventricular or diastolic collapse.
6. The second onflow or diastolic wave.

With frequently beating hearts Morrow states that some of these waves may be absent, or several may be fused together. There is considerable variation in the prominence of the different waves.

The venous pulse represents variations in auricular pressure. In certain cases of disease, waves of blood are sent back into the inferior vena cava, which distend the liver and give rise to a liver pulse. When we have a venous and a liver pulse, the changes that ensue in the tracings of the pulse can be shown by either one.

The venous pulse is a direct means of studying the effects of the systole and diastole of the right auricle and right ventricle and the rate of the auricles.

RAPIDITY OF THE CIRCULATION.

When examining the web of the frog's foot beneath the microscope it is clearly discerned that the rate of the blood's flow through the capillaries is very much less than what it must be in the aorta and its larger branches. That there should be differences in its rate of flow depends upon the same physical reasons as govern the rate of flow in tubes.

The discharge of any liquid through a tube equals the mean velocity multiplied by the area of cross section at the point of observation. The greater the cross section of the area the less the velocity; and conversely, the greater the activity of the heart is to frequency and strength, the greater the velocity. Velocity is less, the greater the peripheral resistance in the capillaries.

The arterial system widens from the center to the periphery. All physiologists admit this proposition, for their opinion is founded upon exact measurements. It has been found that, when there is an arterial bifurcation, the area of the two branches formed exceeds that of the afferent trunk. From experimental demonstration of the widening of the arterial passages, the comparison of the arterial tree to a cone is permissible; its summit is located at the heart, its base at the periphery of the body. The venous system is similarly arranged, the apices of the two systems meeting at the heart.

From this general form of the arterial passages it can be concluded that the movement of the blood must be more rapid in the aorta than in the vessels springing from it, and that the minimum of speed must be in the smallest arterioles. It is known that the cross-sectional area of the arterioles and capillaries is from 500 to

700 times greater than that of the first portion of the aorta; therefore, the velocity of the blood in the capillaries is but $^1/_{500}$ or $^1/_{700}$ of that in the aorta.

Physics show that there is no friction between the walls of the vessels and the contained liquid. The exterior layer of the liquid is *adherent* to the inner surface of the tube and remains perfectly motionless. Between this still layer and the center of the current there are layers of molecules which by molecular cohesion introduce resistances. The next layers adhere to one another less and less the more central they are. Thus the swiftness of the liquid molecules will not be the same in all parts of the vessel, the maximum being reached at the center of the vessel.

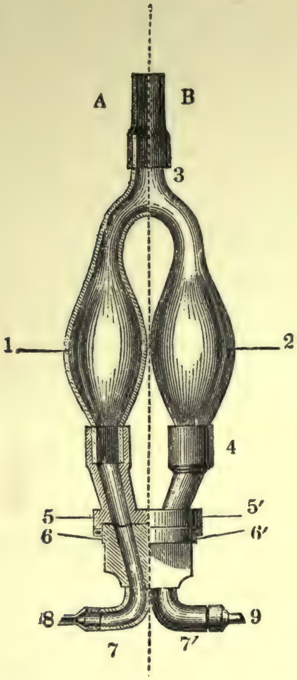

Fig. 104.—Ludwig's Stromuhr. (LANDOIS.)

Rate in the Arteries.—From the relation of the arteries to the main central pump, the heart, the velocity of the blood-flow in them is very naturally greater than in the capillary or venous systems. In rough terms, the average velocity in the large arteries is 12 inches per second. To measure the velocity we employ Ludwig's stromuhr, or rheometer. This instrument consists of two glass bulbs, *1* and *2*, of the same capacity. The ends of these glass bulbs have a common opening above; below they are fixed, at *5-5′*, into a metal disc. This disc rotates around the disc, *6-6″*, so that after a complete revolution a bulb, *1*, communicates with a cannula, *9*, and another bulb, *2*, communicates with another cannula, *8*. This cannula, *8*, is fixed in the central end and the other cannula, *9*, in the peripheral end of the artery (carotid); the bulb, *1*, is filled with oil; the bulb, *2*, with defibrinated blood. At a certain time the communication through *8* is opened, the blood flows in, pushing the oil before it and passes into *2*, while the blood passes through *9* into the peripheral part of the artery. As soon as the oil reaches *4*, the time is noted, and bulbs *1* and *2* are rotated so that *2* takes the place of *1*, and the oil is pushed back into *1* again. The quantity of the blood which passes in a given time is calculated from the time necessary to fill the bulb.

Hürthle has invented a recording rheometer which indicates the quantity of blood that enters and leaves the rheometer. Other instruments have received the names *hæmatachometer, hæmadromometer, dromograph,* etc.

Rate in the Veins.—Whenever the total area of cross section of the vascular tree increases, the velocity of its contained blood-current diminishes; conversely, as the cross section diminishes the flow, becomes proportionately more rapid. The total section of the systemic arterial tree reaches its maximum extent in the arterioles and capillaries. Along the venous tree the cross section diminishes as the heart is neared, but never becomes as small as that of the arteries. Therefore, the greatest velocity must exist in the arteries, the least within the capillaries, while the mean between the two extremes is that within the veins.

Since the venous cross section diminishes as the heart is neared, the velocity of its blood-current becomes heightened accordingly. However, the average rate of venous blood-flow has been estimated to be about 9 inches per second.

Burton-Opitz with Hürthle's instrument found the average rate of flow in the femoral vein of dogs to be 61.6 millimeters per second, whilst in the external jugular he found it to be 147 millimeters per second. Stimulating the vagus arrested the flow in the jugular. The flow of blood in the external jugular was intermittent, due to two types of variation, those caused by respiratory movements and those produced by changes in pressure during each auricular cycle. Inspiration quickens the flow in the jugular, expiration lessens it. During each auricular cycle the blood-flow in the jugular ceases, when the period of rising pressure ensues. He also found in the femoral vein that variations in the venous flow accompanying a tetanic muscular contraction may be divided into three periods: (1) period of great flow synchronous with the muscular shortening; (2) period of slight flow continuing during the contracted state of the muscle; (3) short period of increased flow following the relaxation of the muscle.

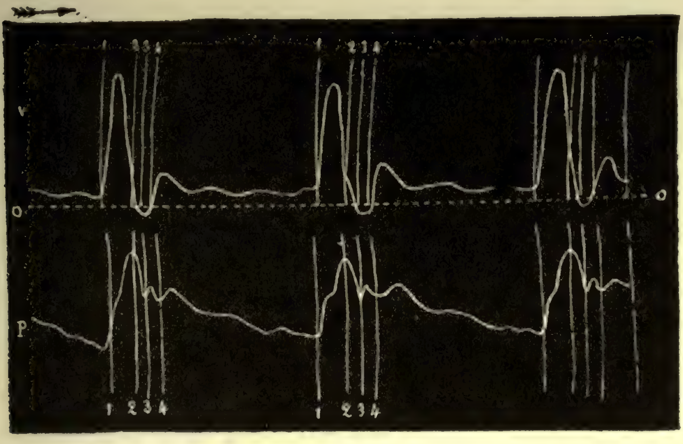

Fig. 105.—Tachogram (*V*), Sphygmogram (*P*), from the Carotid of Horse made with Chauveau's Hæmodromograph and a Sphygmograph at the same time. (LORTET.)

The abscissa, *o*, *o*, corresponds to the zero-line of rapidity. The dicrotic wave is marked on the curve. The slightly curved ordinates drawn through the curves indicate corresponding points on the two curves. The vertical line, 1, indicates the moment the ventricular contraction sends the first systolic wave into the carotid, which calls out simultaneously an increase of blood-pressure and of rapidity of the current of blood. The vertical line, 2, is the time the pressure of the blood has reached its height, whilst the rapidity is decreasing. The vertical line, 3, corresponds to the period when the ventricle has been emptied of blood, and closing of the semi-lunar valves ensued. The vertical line, 4, is the moment of the rebound of the column of blood from the semi-lunar valves and the dicrotic pulse is produced. Between 3 and 4 the rapidity falls below the zero-line and shows a rebound of the rapidity of the blood when the rapid dicrotic rise ensues. From 4 to 1, the curve of arterial tension is slowly falling, and at the same time the rapidity decreases much more slowly.

Rate in the Capillaries.—Even with respect to the capillaries the rule holds good that the velocity is inversely proportional to the area of cross-section. In the frog and in man the velocity has been estimated to be about one-inch per minute.

General Facts in the Velocity of the Circulation.—Marey, from a study of the rapidity of the flow of blood, has arrived at the following conclusions:—

If the resistance increases and the output of the heart remains constant, then the actual tension rises and the velocity becomes less.

If the output of the heart increases and the resistance remains constant, then both the tension and the velocity become greater.

Ludwig and Dogiel state that the velocity of the blood does not depend on the blood-pressure. They state that the velocity in a vessel depends on (1) the *vis a tergo*—that is, the action of the heart; and (2) on the peripheral resistance.

In an animal in repose, the average quickness of the blood continually varies at short intervals. These variations are not dependent upon the temperature of the blood, for it can be made to vary from 104 degrees F. to a very cool limit without perceptibly changing the rapidity. The variations of swiftness are entirely independent of the rapidity of the heart, for the rapidity is different while the beat of the heart has not altered. The changes of rapidity in the different vessels are independent of the average aortic pressure or the pressure which exists in the arteries. There is no proportional relation between the variations of swiftness in the different arteries, for comparative experiments made at the same time in the carotid and crural artery show that the rapidity is greater now in one, now in the other of these vessels. The variations of swiftness in these vessels are at the same time independent of each other. The changes of rapidity of the flow in the arteries depends solely upon the obstacles which the blood, when injected, meets in its course, especially when the obstacles are encountered by the flow of blood in other arteries at the same time; for example, the resistance in the arteries of the intestine increases the rapidity of the flow in the vessels of the brain notwithstanding the obstacles in these vessels. The intestinal circulation regulates the flow in other arteries, and particularly in the carotid. The obstacles met with in the rapidity of the circulation in vessels depend upon the innervation of these vessels by the different vasomotor nerves. This innervation oscillates; hence the swiftness is not the same in two arteries of the same caliber. Section of a vasomotor nerve does not prevent variations in the rapidity in the territory innervated by that nerve, since neighboring territories under the control of other vasomotor nerves can react upon the flow of blood in the part with the divided vasomotor nerve. When one carotid is ligated the velocity in the other increases.

Section of the vagi increases the velocity by increasing the amount of blood ejected by the ventricle.

Systole of the heart increases the velocity; diastole decreases it.

Duration of the Circulation as a Unit.—The general rapidity of the circulation—that is, how long a time an entire circulation occupies—may be easily determined experimentally in a living animal. This was first accomplished by Hering, whose principle of action was to compute the time required for the circuit of an injected, harmless substance. The substance taken is one that may be easily recognized by chemical test; sodium ferrocyanide is the one least injurious to the heart. He injected a 2-per-cent. solution into the central end of a divided jugular vein, and the time of injection was carefully noted. From the opposite jugular, samples were taken as quickly as possible, the time of each being noted. When the Prussian blue reaction was obtained in any sample, the time of its withdrawal gave the duration of the entire circuit. In this experiment the blood containing the solution passed to the right side of the heart, through the lungs to the left side of the heart, from thence into the aorta to be distributed through the smaller vessels and capillaries of the head and face, to return by the jugular veins.

This jugular-to-jugular result does not represent the circulation of the entire blood-supply of the body, but the shortest time that a drop of blood may traverse the shortest pathway along both the systemic and pulmonic circulations. It is impossible thus to determine the circulation time of the entire blood.

From the result of experiments it has been ascertained that the circulation time in the horse is 31.5 seconds; in the dog, 16.7 seconds; in the rabbit, 7.79 seconds.

Another method is that of Professor G. N. Stewart. He injects into a rabbit methylene blue per jugular, and then, watches the appearance of the coloring matter in the opposite carotid. Under the carotid he places a thin sheet of India rubber and between this and the artery a little piece of white, glazed paper. Then, noting the time when blood is injected per jugular and the time of its arrival in the opposite carotid, he determines the duration of the circulation. In the rabbit he made the jugular-to-jugular time from 5 to 7 seconds.

The above method merely gives the shortest possible time in which a particle of blood can travel through the shortest pathway.

In man the time it takes the blood to make a complete circuit of the body is about 32 seconds.

COURSE OF BLOOD IN THE VENOUS SYSTEM.

When the blood has undergone within the general and pulmonary capillaries the changes which result from processes of nutrition and oxidation, it returns to the heart. It is the *venous system* which is charged with this centripetal transportation.

Has the action of the heart anything to do with the progression of the venous blood? To-day, all the world recognizes that it is the cardiac impulsion which, after having driven the blood through the capillaries, still presides. That is, the venous blood-current is maintained primarily by the *vis a tergo* (force from behind). In other words, it is what remains of the systolic energy of the heart transmitted through the arteries and capillaries. The *elasticity* of the venous walls themselves aids, to a slight extent, the movement of the blood by their rather feeble contractions. Contraction of the *skeletal muscles, aspiration* of the *heart* and *thorax* are factors also; the last-named condition creates the *vis a fronte.*

As the pulse-wave is normally caused to disappear in the capillary network, so also the blood-pressure must suffer materially; in fact, it continues falling even along the course of the veins until the heart is reached. Nowhere along the venous system is the positive pressure more than the merest fraction of what is found along the arterial tree. In the right side of the heart and the thoracic portions of the great veins the pressure may even be negative; that is, less than the atmospheric pressure. In the small venous radicles coming from the capillary system the blood-current is more rapid than in the capillaries themselves, but far from the speed of that attained in the corresponding arterioles.

There must of necessity be other influences exerted at this stage, since the energy which the systole of the heart has put forth has been greatly expended before it reaches the veins.

At the head of the list of factors conducive to venous flow, other than cardiac systole, stand the contractions of the skeletal muscles.

The contraction of the muscles aids the passage of the venous flow somewhat as follows: When pressure is brought to bear upon the vein with its contents at any particular point naturally the contained blood will endeavor to escape in two directions. That escaping toward the capillary system is soon checked by the closing of the first pair of valves, so that this portion of the vein becomes swollen and distended, but firmly holds the blood. The closure of the valves allows a current to be established in but one direction, and that *toward* the heart, thereby assisting venous flow in proportion to the extent of pressure exerted. In the limbs is found this aid to venous circulation. Should the muscles remain in a state of tetanic contraction, the venous blood passing out collects in the subcutaneous system, for it must be remembered that particularly numerous anastomoses with one another, as well as the deep with the superficial veins, are characteristic of this system. That the muscles aid venous flow is nicely demonstrated by the increased flow from an incised vein during contraction of its adjacent muscles when performing venesection.

The action of the diaphragm and intercostals helps to render the intrathoracic pressure negative during inspiration; so that the blood is *drawn* from the peripheral portion of the venous tree toward the heart; as some observer states it, the blood-column is actually lifted in the ascending vena cava.

Another, though less important, factor in venous propulsion is *thoracic suction.* For every time that the chest expands and makes in its interior an empty space, air rushes in to fill the same. The venous blood, situated in the vicinity of that cavity, also is helped into its intrathoracic veins.

Pathological.—By standing during the whole day barbers and others have varicose veins. Walking would counteract this by muscular contraction emptying the veins. The tone of the skin also has an effect.

Circulation in the Brain.—Dr. Leonard Hill states that the brain content of blood can vary suddenly only to a slight degree, and that Monro's doctrine is to all intents and purposes true. When the aortic pressure rises the expansion of the cerebral volume can take place only to a certain limited degree, for as soon as all the cerebro-spinal fluid is driven out from the cranium the brain everywhere is in contact with the rigid skull. We have in the vasomotor center a protective mechanism by which blood can be drawn at need from the abdomen and supplied to the brain. At the moment of excitation from the external world the splanchnic area contracts and more blood is driven through the brain. The quantity of the blood in the brain is nearly the same, but the rapidity of the circulation in the brain varies. Thus, should there be any evidence of cerebral congestion, the splanchnic fibers dilate the vessels in its area and by so doing decrease the amount sent to the cavity of the cranium. Should cerebral anæmia occur the reverse will be the condition of affairs in the splanchnic area.

If the pressure in the large veins increases, whilst that of the aorta is the same, then there is more blood in the cranial veins, less in the cranial arteries and a slowing of the rapidity of circulation in the brain. If the pressure in the aorta is elevated and that in the large veins remains the same, then the cerebral arteries contain more blood, the veins less and the rapidity of the cerebral circulation is accelerated. Howell found that a rise of pressure, however great, in the cerebral arteries does not cause directly any impediment to the blood-flow, either temporarily or permanently. The circulation in the brain behaves in this respect as it does in other organs of the body: the greater the arterial pressure the more abundant is the flow of blood, and temporary anæmia can not be produced in this way.

The existence of vasomotor fibers in the brain is still a subject of debate.

VASOMOTOR NERVOUS SYSTEM.

Thus far the circulatory system, except the heart, has been considered almost entirely from its physical standpoint: that it is a system of more or less elastic tubes through which the blood is propelled by the action of the heart. There was considered the resistance which its passage met with, the pressure exerted by this vital fluid, together with the interpretations and the physical causes for variations in each function or property. It yet remains to consider that they are *living* tubes, and that they and the heart are kept in a very delicate balance by reason of certain physiological mechanisms. The agents governing their functions are impulses that emanate from the central nervous system *via* certain nerves. The circulatory apparatus, as every other system, or organ, or part of the entire economy, is under one management and direction located within the central nervous system. It is this latter system that, by the maintenance of its functions, produces harmony and division of labor throughout the entire body.

It has been previously stated that the musculature of the heart is under the guidance of two sets of nerve-fibers: one set to restrain heart-action; another to increase it. Likewise there are *two* sets of fibers which supply the musculature of the vessels (particularly the arterioles, since their proportionate quantity of circular, unstriped muscular fibers is greatest), which, together with their *centers,* constitute the *vasomotor system.*

The *vasomotor* system may be said, then, to be composed of the *vasomotor center,* situated in the medulla, together with some accessory and subsidiary centers in the spinal cord, and *vasomotor nerves.* The nerves are divided into *two classes,* according as they increase or diminish the caliber of the arterioles: those which increase the caliber are *vasodilators;* those which diminish the same are known as *vasoconstrictors.* All nerves that in any way influence vessel-caliber are classed under the general head of vasomotor.

How the Nerves End.—The manner in which the nerves end in the walls of the blood-vessels is an important subject. According to the majority of histologists, they end in the circular muscle of the arterioles. With the exception of the portal system, there has not been established any direct proof of function of vasomotor nerves in regard to the venous system.

Stilling, in 1840, knew that the vascular nerves ran in the sympathetic, and he named these nerves vasomotors. Claude Bernard, in 1851, found that after section of the cervical sympathetic the blood-vessels of the ear dilated and the ear became warmer. In 1852, Brown-Séquard discovered that electrical irritation of the cranial end of the sympathetic was followed by a contraction of the blood-vessels, and that this contraction was followed by a cooling of the ear.

In 1858, Bernard found that when the chorda tympani was irritated the blood-vessels, instead of being constricted, were dilated. To such an extent did dilatation occur that the blood in the vein acquired, instead of a blue color, a red color. The veins themselves became swollen in size.

These various observations tend to prove that there are two kinds of vasomotor nerves: *vasoconstrictors* and *vasodilators.*

Functions.—Ordinarily the arterioles are in a state of tonicity—moderate contraction—to maintain peripheral resistance; otherwise the flow of blood through the capillaries would be intermittent instead of continuous, as it normally is. It is when this peripheral resistance is low that there appears a capillary and venous pulse.

In hot weather the capillaries of the skin dilate; in cold weather they contract.

Another very important function of the vasomotors is their regulation of the amount of blood-supply to any part, organ, or gland of the economy. That is, they govern the amount found within the arterioles and capillaries of the tissues.

The vasoconstrictor nerves arise from a center in the medulla oblongata, pass down the lateral columns, and establish communication with minor vasomotor centers in the spinal cord, and then from there the vasomotor fibers emerge from the anterior roots to reach the blood-vessels.

When a vasoconstrictor nerve, as the sympathetic, is cut, the blood-vessels of the rabbit's ear supplied by it *dilate*. This fact indicates that the circulatory vessels have tonic impulses going to them from the central nervous system through the vasoconstrictor nerves.

This *tonus* of the vasoconstrictor nerves does not exist in all vasomotor nerves to the same degree. It is a variable factor—may be depressed or absolutely removed. To decide that a nerve is a vasoconstrictor nerve, it becomes necessary to irritate the nerve with an electrical current and then to see the blood-vessels supplied by it contract.

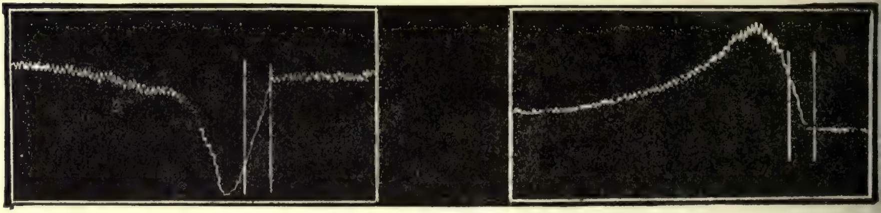
A B

Fig. 106.—Curves Obtained by Enclosing the Hind Limb of a Cat in the Plethysmograph and Stimulating the Peripheral End of the Cut Sciatic Nerve (Bowditch and Warren, 1886). (Howell.)

The curves read from right to left. In each case the vertical lines show the duration of the stimulus, namely, fifteen induction shocks per second during 20 seconds. Curve *A* shows the contraction of the vessels produced by an equal excitation of the freshly divided nerve; curve *B*, the dilation produced by an equal excitation of the nerve of the opposite side four days after section, the vasoconstrictor nerves having degenerated more rapidly than the vasodilators.

When *tonus* exists in a vasoconstrictor nerve and it is then *cut*, there results an effect *opposite* to that of an irritation. That is, there is a condition of dilatation in the arterioles and capillaries. By this section of the vasoconstrictors the volume of the parts increase in direct proportion to the increased blood-supply. If a cut be made into the organ, the blood flows more rapidly than before there was section of the nerve. The temperature of the organ increases and is perceptibly higher than that of the opposite side.

With increase in dilatation there is a concomitant *fall* in blood-pressure. If a large vasoconstrictor nerve like the splanchnic be cut, then the blood-pressure is marked by a most decided fall.

If, now, the vasoconstrictor be irritated, preferably with electricity, phenomena that are opposite to those just detailed ensue. The arterioles and capillaries become so contracted that they are no longer visible; the size of the organ supplied by these nerves diminishes; the venous blood becomes dark. If you cut the organ, less blood flows out of it than when there is paralysis of the constrictors and, therefore, dilatation.

The vasomotor nerves are always in a condition of antagonism, although the constrictor influence is by far the more powerful. Thus, if a nerve-trunk which contains both constrictor and dilator fibers be stimulated, the first effect is constriction of the arterioles and capillaries supplied by the artery. This condition of constriction lasts for some time, but is eventually replaced by dilatation of the vessels of the part. This dilatation is a sequel, and is to be explained by the fact that the vasodilator fibers are less easily exhausted than the vasoconstrictor fibers. For, after separation of the vasomotor fibers from the central nervous system, it is found that the vasodilator fibers do not lose their excitability before the lapse of from *six* to *ten* days. The vasoconstrictor fibers do not respond to excitation after the third or fourth day.

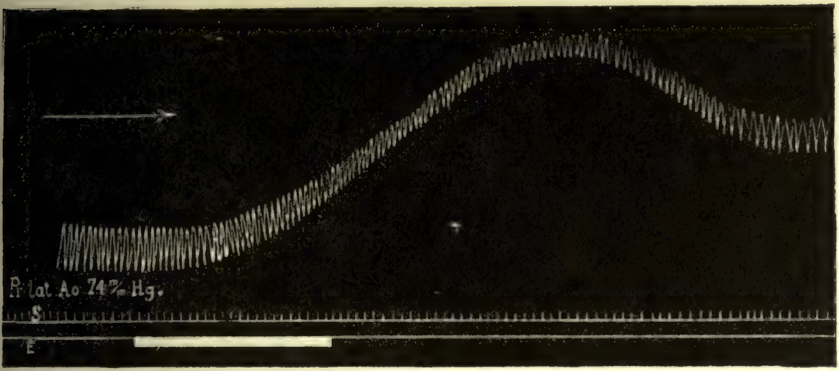

Fig. 107.—Effect of Irritation of the Splanchnic Nerve on the Aortic Pressure. (GLEY.)

Dog with medulla divided. *Pr, lat. Ao,* Aortic pressure. *S,* Time in seconds. *E,* Faradic irritation of the peripheral end of the left splanchnic.

Vasoconstrictors of the Head.—It is known that the cervical sympathetic is the vasoconstrictor for the corresponding side of the face, ear, cheeks, lips, brow, eye, middle-ear, and tongue, with the submaxillary and parotid glands; in fact, all parts of the head with the exception of the brain are supplied by it. The vasoconstrictors of the head leave the cord by the first five dorsal nerves, pass through the stellate and inferior cervical ganglia, go up in the cervical sympathetic as preganglionic fibers to the first cell station, the superior cervical ganglion. From here postganglionic fibers go to the Gasserian ganglion and in the trigeminus and its branches. Other fibers go from the superior cervical ganglion on the walls of the carotid artery and its branches.

The constrictors of the ear come from the sympathetic; go by the cervical plexus in its second and third branches and to the ear by the auriculo-cervical.

Vasoconstrictors of the Extremities.—The vasoconstrictors of the upper extremities leave the cord by the dorsal anterior roots from the fourth to the tenth, go in the sympathetic to stellate ganglion, then into the brachial plexus and the nerves which leave it; some do not enter the sympathetic but leave the cord directly with the roots of the nerves of the upper extremity. The vasoconstrictors of the lower extremities leave the cord by the roots of the lower dorsal and the first three lumbar, enter the thoracic and abdominal sympathetic and go into the sciatic. Some fibers leave the cord directly with the roots of the sciatic and crural without entering the sympathetic.

Vasoconstrictors of the Abdominal Viscera.—The vasoconstrictors come from the dorso-lumbar cord. The vasomotors of the abdominal viscera leave the dorsal cord from the lower fifth dorsal down and the lumbar cord by the first two or three roots. Branches from the fifth to tenth thoracic ganglia form the splanchnics, then go into the cœliac plexus and from there to the various organs as the intestines, liver, spleen and kidneys in the plexuses which surround these organs. Some vasoconstrictors descend by the vagus to the stomach, the intestine and the kidney. The vasoconstrictors of the genital organs leave the cord by the second and third sacral and go in the hypogastric plexus, where they pass to their destination.

If one splanchnic be cut in the abdominal cavity, the blood-pressure sinks 30 or 40 millimeters; if the second be cut the pressure immediately drops to 10. If the peripheral end of the cut nerve be irritated, the aortic pressure ascends and reaches as great a height as before section. Through the paralysis of the abdominal vessels the portal system is filled with blood, the small intestinal vessels are strongly injected, the blood-vessels of the kidneys are dilated, and the renal tissue is red and congested.

By these experiments it was established that the splanchnic is the most important of all the vasoconstrictor nerves, and therefore an important regulator of the blood-pressure. The splanchnics supply vasomotor fibers to the stomach, bowels, and kidneys. Irritation of one splanchnic is sufficient to cause vasoconstriction in both kidneys.

The viscera receive vasoconstrictor fibers from other sources, as the vagus. Two weeks after section of both splanchnics beneath the diaphragm, the blood-pressure is again found to be the same as that of a normal animal.

The elevation of a patient in bed may lead to a faint, because the heart in a reclining position and the abdominal reservoir of blood are on the same plane; but the erect position increases the work of the heart because the abdominal reservoir of blood is lower.

Vasoconstrictors of the Thorax.—They arise from the five upper dorsal nerves, go out through the first thoracic ganglion, then through the annulus of Vieussens to the inferior cervical ganglion, and pass to the heart and lungs. But direct observation shows that the vasoconstrictors of the lungs are not strongly developed. An obstructive lesion of the left heart will elevate blood-pressure in the lungs.

Vasodilators.—The *vasodilators* originate from a principal center, located in the medulla oblongata, and from subsidiary centers distributed throughout the spinal cord.

The salivary glands receive their vasodilators from the glosso-pharyngeal for the parotid and from the facial for the submaxillary. The same nerves furnish vasodilators to the anterior two-thirds of the tongue by a branch from the chorda tympani, and by the glosso-pharyngeal to the posterior third of the tongue. The mucous membrane of the lips, cheeks, palate, nasal fossa receive their vasodilators from the trigeminus by the superior maxillary branch. These vasodilators in the superior maxillary are the outflow in the facial which goes to the spleno-palatine ganglion. The outflow of vasodilators in the glosso-pharyngeal go to the otic ganglion, whence they pass into the inferior maxillary to the mucous membrane of lips, cheeks, palate and nasal fossa.

Those for the ear leave the cord by the eighth cervical and the first and second dorsal, go to the first thoracic and inferior cervical ganglia up into the cervical sympathetic. The vasodilators of the upper extremity leave the dorsal cord by the fifth, sixth, seventh and eighth pair, and the vasodilators for the lower extremities by the fifth, sixth and seventh lumbar pair in the dog. The vasodilators of the abdominal viscera leave the cord from the second to twelfth dorsal pair of nerves and from the first to second pair of lumbar nerves and some enter the splanchnics. The vasodilators of the penis, nervi erigentes leave the cord by the anterior roots of the first, second and third sacral and go into the hypogastric plexus. The vasodilators of the laryngeal mucous membrane come by the pneumogastric for irritation of the peripheral end of the superior laryngeal makes the mucous membrane red.

All the facts show that, with the exception of the vasodilators, which flow in the different cranial nerves, the majority of branches are found mixed with the vasoconstrictors in the sympathetic trunks, and the same nerve, like the sciatic, can give vasoconstriction or vasodilation. The muscles are mainly supplied with vasodilators.

The results of irritation of the vasodilators are necessarily opposite to those which result from an irritation of a vasoconstrictor. With vasodilators the blood-pressure falls in the dilated vessel and the veins by the increased flow of blood have an elevation of pressure, the organs supplied by these nerves become red and their volume and temperature increase.

All vasomotor nerves are distributed to *unstriped, involuntary* muscles; spinal nerves to *striped voluntary* muscles. The former are always characterized by being ganglionated; in other words, possessing cell-stations, or relays, in their course from the central nervous system to the muscular fibers which they govern.

The vasodilator nerves behave very similarly to the cardiac branches of the vagus, for, when both are stimulated, the result produced is inhibition and relaxation. Nicotine is said to be a powerful excitant of the vasodilators.

Recognition.—It is easy to recognize a vasodilator nerve when it contains no other fibers. But, should it be mixed with vasoconstrictors going to the same organ, it becomes necessary to make special arrangements. These are occasioned by the fact that the vasoconstrictors usually overcome the dilators. However, the constrictors become tired more quickly, and after they are exhausted the vasodilators act.

By warming or cooling an extremity with water, the experimenter can, on irritating a nerve, obtain a dilatation or a narrowing of the blood-vessels supplied by it. When in the same nerve two kinds of vasomotors run, then by the same irritation in warming the foot there is obtained a contraction of the vessels, and in the second place a dilatation on cooling the foot.

Differences in Two Kinds of Nerves.—Vasomotor nerves present differences in their actions dependent upon division and degeneration in the same. After degeneration, an irritant to a nerve calls out vasodilation, while to a nerve in the fresh state the same irritant produces a primary vasoconstriction.

By variation in the frequency and strength of the irritation there is afforded a means to differentiate the two kinds of nerves which may traverse the same nerve trunk. The vasodilators are excited by *weak currents* and *slow rhythm.* The vasoconstrictors are irritated by *stronger currents* and *greater frequency* of irritation.

Theory of Vasodilator Action.—The vasodilators act upon the circular arterial muscle directly. How they act is still hypothetical. Since physiologists know of no muscle through whose contraction the blood-vessels become more dilated, it is assumed that vasodilation is due to a *paralysis* of the circular fibers of the vessels. That is, the dilators must be inhibitory or vaso-inhibitory nerves.

The *tonus* of a blood-vessel depends partly upon impulses from the central nervous system via the vasoconstrictors. It is upon the circular muscles that the dilators are supposed to exert an inhibitory action.

Frequent allusions, during the discussion of the vasomotor system, have been made to the effects of experiments upon various vasomotor nerves. They have been nearly all performed upon animals, and consist, in the main, of *section* and *excitation* of various kinds: electrical, thermal, etc. By these means much has been learned concerning this very important system—important to the physician as a means of explaining many pathological conditions.

Vasomotor Centers.—The *main vasomotor center* lies in the floor of the fourth ventricle in its gray matter. It is located on each side of the median raphé, and extends three millimeters from a little above the nib of the calamus scriptorius to near the corpora quadrigemina. Its position was determined by noting that when it was destroyed there was a lack of tonicity displayed by all of the arterioles, with a consequent fall in blood-pressure. When this same area was stimulated all of the arterioles were constricted, giving a rise in blood-pressure as a sequel. Section of the cervical spinal cord permits all the arterioles to dilate as the main vasomotor center has been cut off and the blood-pressure falls to 10 millimeters.

SPINAL VASOMOTOR CENTERS.—Experiments demonstrate that with the destruction or paralysis of the main center there results a drop in blood-pressure; if, however, the animal be kept alive by artificial respiration, after a variable length of time the arterioles regain their tonicity and there is a corresponding rise in pressure. This phenomenon is accounted for by the presence of minor or subsidiary centers, which in the emergency have risen in their functional abilities. These minor vasoconstrictor centers exist in the spinal cord. They may be excited in a reflex manner by means of strychnine (Ott and Klapp).

Upon destruction of the cord there follows a second fall of pressure, with dilatation of the arterioles.

Even when the spinal cord is destroyed in great part the tonus of the vasomotor system is gradually regained so that heat and cold applied to the skin have the same reaction take place as in normal conditions of the vasomotor system. It is probably the circular muscles of the blood-vessels which exert this tonic influence after destruction of the spinal cord.

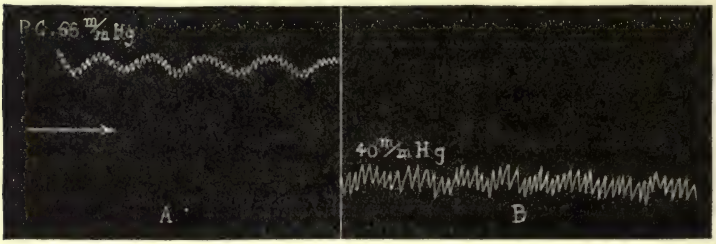

Fig. 108.—Carotid Pressure in Curarized Dog after Section of Medulla *A*, and after Destruction of the Cord *B*. (Gley.)

Normal pressure was 120 millimeters. After section of the medulla it fell to 66 (*A*). After destruction of spinal cord it fell to 40 millimeters (*B*).

The vasoconstrictor center is in a state of *permanent excitation,* which produces vascular tonus; this is not the case with the vasodilator center.

In a totally relaxed vascular system there is no possible circulation—the blood stands still. During extreme dilatation the heart receives but little blood, so that but very little is driven out of it during systole. Hence the tonus of the blood-vessels is a necessary condition for the circulation.

The tonus of the veins is dependent upon the central nervous system, and is quite as important as is that of the arteries.

The vascular tonus is continually a seat of slight fluctuations, of which the most important when depicted graphically constitute the curves of Traube. The curves are the products of oscillations of the vascular tonus. The oscillations are caused by variations in the automatic excitation of the vasoconstrictor centers. (See "Traube-Hering Curves.")

The vasoconstrictor center is excited during dyspnœa and asphyxia. This occurs on account of the accumulation of carbonic acid in the blood. This action explains why the arteries in the cadaver are free from blood. Strychnine, nicotine, and Calabar bean also excite the vasoconstrictor center.

Advantages of Vessel Innervation.—By reason of vascular tonicity the diameters of the vessels are a trifle too small to contain all the blood; so that the vascular walls are obliged to dilate. The result is pressure and circulation of the blood.

When various organs and parts of the body are in activity they require an excess of blood. This surplus is furnished by a dilatation of the capillaries of the part. Ludwig compared the vasomotor centers to turn-cocks in a great city. They turn off the water-supply from one district and at the same time turn it on in another.

As previously stated, the cutaneous circulation regulates the losses of heat.

When, from the influence of cold, the capillaries of the skin are narrowed, the internal organs are congested. Under the action of heat the skin is congested and the internal organs made anæmic. This increase in the blood-supply in those parts where needed has been ingeniously demonstrated by Mosso. He placed a man upon a very large board which was most delicately balanced at its center. By use of it he demonstrated that whenever the man began to think the increased blood-supply in his brain caused the head to go down and the heels to rise up.

In muscular work the vessels of the muscles and skin are dilated, whilst the intestinal arterioles supplied by the splanchnics are contracted; hence the arterial tension is increased.

About one-half the blood in the body is stored up in the thorax and abdomen; hence it can quickly supply a large amount of blood to any organ in activity which needs it. The kidney when compared with other organs receives a large quantity of blood for its important duties of removing the waste matter from the body.

Vasomotor Reflexes.—The afferent nerves stand in relation to the main vasomotor center in such a way that they can either excite or inhibit its activity. A pressor nerve is one which when stimulated reflexly excites the vasomotor center and produces a rise of blood-pressure. A depressor nerve is an afferent nerve which when stimulated inhibits the activity of the main vasomotor center. In the afferent nerves we have these two kinds of fibers—pressor and depressor. The pressor fibers are especially found in the nerves of the skin.

If an afferent nerve is cooled, or after section allowed to regenerate to a certain extent, or the stimulus is weak, then when irritated, it may produce a fall of blood-pressure.

The vasomotor reflex ensues primarily in the same vascular location where the afferent irritation is made. This explains the congestion of the intestines upon opening the abdominal cavity and the injection of the skin after friction or warmth. Generally the localized reflexes cause a vasodilation, but it may be a vasoconstriction which may spread to the opposite half of the body, or to parts at a considerable distance, as the arterioles of the intestine innervated by the splanchnic nerves. If one hand be plunged into ice-water, the blood-vessels of the opposite hand also contract.

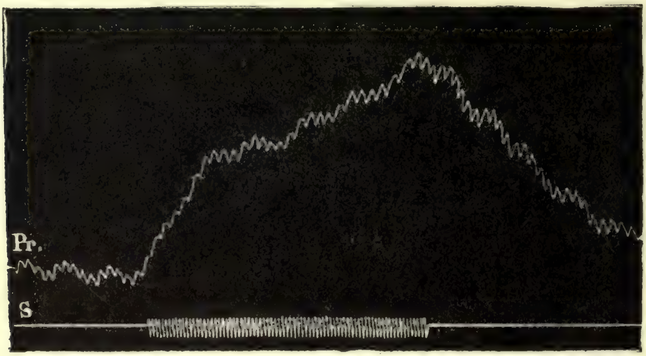

Fig. 109.—Elevation of Arterial Pressure by Vasoconstriction. A result of irritation of the central end of sciatic in curarized dog. (Hedon.)

P, Carotid pressure. *S*, Signal-magnet tracing.

Vasomotor reflexes can take place through the vasodilators for Bayliss has shown that after removing the influence of all the vasoconstrictors of the posterior extremity, vasodilation ensued in the same region by stimulating the vagus.

In the chorda tympani and nervi erigentes are nerves which cause a vasodilation from afferent impulses, presumably from an action on a vasodilator center.

Fear blanches the face by a psychic action on the vasomotor centers, whilst blushing is a result of a psychic effect on the same centers.

As the blood-vessels are often dilated at one place and contracted at another in the body from the same sensory stimulation, the blood-pressure may be increased or decreased in these regions.

Irritation of the nerves of testes and middle ear usually lower blood-pressure. As a rule, irritation of a sensory nerve of the skin is followed by a contraction of the blood-vessels, and especially those supplied by the splanchnics. The rise which is created depends upon the strength and nature of the stimulus. During this condition there is vasoconstriction of the splanchnic vessels, while at the same time the blood-vessels of the skin and muscles are more or less dilated.

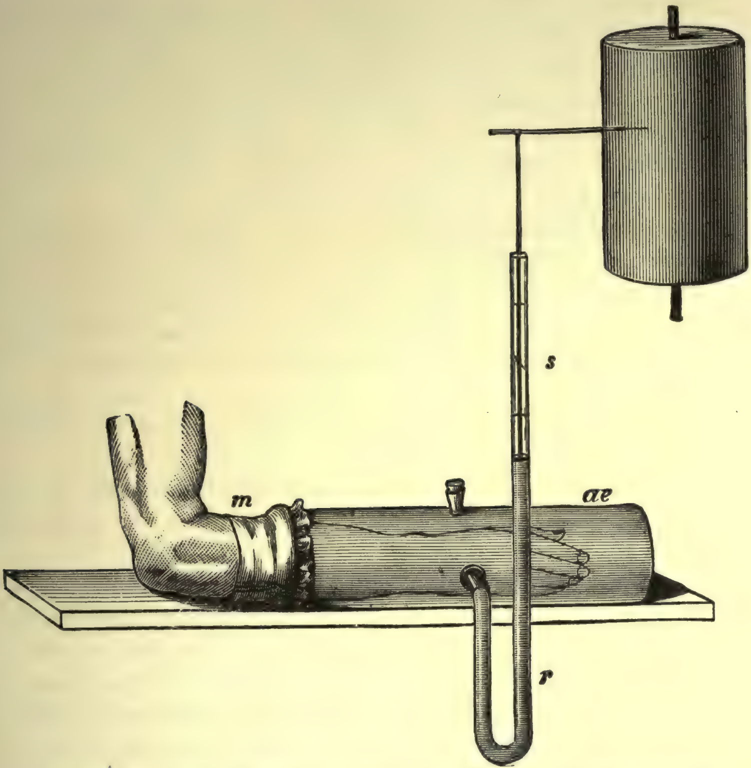

Fig. 110.—Fick's Plethysmograph. (From Tigerstedt's "Human Physiology," copyright 1906, by D. Appleton and Company.)
ae, Glass cylinder. *m*, rubber band to close the glass cylinder. *r*, *s*, Registering manometer.

The nervous depressor by irritation of its central end lowers blood-pressure. The condition of depression is due to a vasodilation of the arterioles, especially of the vessels supplied by the splanchnics.

Hence, in the reflex relation of the afferent nerves to the vasomotor centers there are two kinds of fibers, pressor and depressor. (1) The pressor fibers cause a vascular narrowing, due to a reflex stimulation of the vasoconstrictor center. (2) The depressor fibers cause dilatation of the arterioles and a fall of arterial blood-pressure, due to reflex inhibition of the vasoconstrictor center, as with the nervous depressor.

There are also reflex vasodilator fibers, which lower arterial blood-pressure by a stimulation of the vasodilator center, as in the congestion of erectile tissue and the afflux of blood to glands in activity.

The vasomotor changes can be studied by means of instruments which register the changing volume of a part at each systole of the heart and the varying diameter of the arterioles. These instruments are known by the names of *plethysmograph* and *oncometer.*

Pathological Conditions of Circulation.—In mitral regurgitation the dilatation and hypertrophy of the left side of the heart are due to the blood running back from the ventricle at each systole. This state of affairs keeps the auricle overfilled, and the backing of the blood causes congestion in the pulmonary capillaries, which results in cough and dyspnœa.

Sudden death can result from a thrombus of the coronary artery or an obliterating arteritis of this vessel.

The secretion of the urine is, to a great extent, under the varying arterial tension due to vasomotor activity. In fever the vasomotor system is concerned in the flushing of the face and body.

Hutchison states that the missing of beats in the pulse may be caused by excess of excitability in the auricles, so that they contract before the ventricles have finished their systole, or to occasional want of conduction from auricle to ventricle in the muscle; or by an excess of excitability in the ventricles, so that they contract before the impulse arrives from the auricle, hence, when this impulse does arrive the ventricle is refractory and does not respond. We can separate the causes in part by the fact that ventricular intermission, during which the auricle continues to beat regularly, must always be twice as long as the ordinary pulse interval.

Clinical experience teaches that irregularity of the heart seems especially to take place when the auricle is diseased. There is a form of irregularity of the heart due to a want of synchronism in action between the two auricles or two ventricles respectively or between the two sides of the heart as a whole.

Cardiac Dyspnœa.—Dyspnœa of heart disease is due to insufficient oxidation of a slowed blood-current and to effect of CO_2 on the center of respiration. Changes also take place in the epithelium of the alveolus.

Cardiac Pain.—Pain in the heart is due to disease of the coronary arteries and of the origin of the aorta.

Excess of Circulating Fluid.—The continuous drinking of large quantities of water may cause the heart to increase its systolic force to overcome the increased amount of circulating fluid but finally it may fatigue itself, weaken and cease acting. Hence an excess of drinking of fluid is injurious in weakness of the muscular structure of the heart.

Effect of Various Conditions.—Exercise, mental work, rage and cold elevate blood-pressure; the last two causes often produce apoplexies. Heat, rest and sleep depress the arterial tension.

Pharmacological.—Adrenalin greatly elevates blood-pressure by an action on the muscular structure of the arterioles, or, according to Langley, by an action on the myoneural substance. Amyl nitrite or nitroglycerine lowers arterial tension chiefly by an action on the walls of the arterioles. Adrenalin, when given with nitroglycerine, overcomes its action on blood-pressure.

Urea increases arterial tension by an irritation of the vasoconstrictor center. On the vessels of the kidney urea acts locally as a vasodilator.

CHAPTER VII.

RESPIRATION.

THE study of digestion and circulation has taught the reader the nature of the methods and the avenues along which ingested materials must pass in the processes of their elaboration in order to maintain the requirements of life. It has also made him acquainted with the various forms under which those materials became absorbable and miscible with the blood, and which must necessarily be renewed in proportion as the latter is changed by the nutrient movement. It is known, too, that the liquid and soluble products of digestion and the lymph itself, when poured into the venous blood, do not have the qualities of a directly nutrient fluid immediately after their mixture with the blood. In order that these qualities should develop it is necessary that there should occur the intervention of an essential element, which animals find in, and incessantly draw from, the enveloping atmosphere—oxygen. The latter is the great agent in the final transformations which the various organic matters must undergo. The introduction of a certain proportion of oxygen into the economy is, therefore, the first aim of the function of respiration.

The general tendency of the various gases to mingle even when wet membranes separate them has been pointed out. Looked at in its essential character, the respiration of animals consists in a single exchange of gases which takes place during the action exercised by the air upon the blood. In fact, atmospheric oxygen, brought into contact with a thin, membranous wall, passes through it and penetrates the blood, while the carbonic-acid gas contained in that liquid is freed from it through the same membrane. Therefore, if respiration, on the one hand, takes something away from the blood, on the other, it communicates to it a principle which renders it suitable to complete the organs, furnish material for their secretions, or to repair their losses, while, at the same time, it gives rise to a disengagement of heat indispensable to the free exercise of the functions. It is this vivifying principle which combines with the organic matters of the blood to form the water and carbonic acid that are unceasingly eliminated by expiration and which are soon decomposed in the atmosphere under the influence of solar radiation, to furnish carbon and hydrogen to vegetation.

The blood, with its complex constitution, becomes in this way the principal medium for all the phenomena of nutrition. It is known to be collecting, in its course, for its own reconstitution, certain materials elaborated by the digestive passages and then depositing assimilable principles in the various tissues. The blood represents, therefore, a reparatory fluid whose continual renewal and destruction, intrusted to *digestion* and *respiration,* constitute the two inseparable conditions for existence of the higher animals.

When air is fed to the wood in the firebox of a boiler a process known as burning takes place. It is a real chemical process: the oxygen unites with the carbon and hydrogen of the wood, so that both the wood and oxygen disappear as such. The carbon and a portion of the oxygen unite to form *carbonic-acid gas.* The hydrogen and the remainder of the oxygen by their union form *water.* The two substances thus formed pass off in the smoke, leaving behind as the *débris,* or ashes, the *mineral* part of the wood. By this burning also termed *oxidation,* heat and a flame are produced.

Within the body there occurs an analogous process, also termed oxidation, whereby the oxygen inhaled into the body slowly burns the protoplasm of *cells* in a manner similar to the burning of the wood in the boiler. This process within the body is performed so slowly that there is no appearance of a flame, but there is yielded the same amount of heat as would be produced were the same materials burned within a furnace or stove. Some of this heat is utilized to give warmth to the body, while the remainder of it is converted into power and energy, so that the body may do work, either of motion, thought, or manufacturing the various products of the body. Oxidation is the essential process of life; when it ceases, life ends. It occurs in *every* cell of the economy. Its degrees of oxidation in the living cells can be heightened or lowered according to the needs of the body. The end-products of body-oxidation are also carbonic-acid gas, water, and ashes, or urea as occurred in furnace oxidation.

From studies in general physiology it is known that the peculiar form of *energy* which is called *life* exists only in association with living cells or living organisms. It is liberated during a catabolism, or destructive metabolism of living cell-protoplasm, and this metabolism is possible only in the presence of oxygen. During these catabolic metabolisms the living protoplasm of the cell, the deeply complex protoplastic molecule, is split up into two, perhaps more, simpler molecules; these last, which probably represent proteids, may again separate into still simpler ones. Each change from a complex compound to a simpler one leads to (1) liberation of energy upon which depend the numerous activities of life and (2) to a new combination of the simpler molecules with oxygen. Thus, *oxygen is the cause of combustion, and the complement of catabolism.*

Respiration is the general term that includes all of those activities that are involved in the furnishing of oxygen to the tissues and the removal of CO_2 from the tissues of a living organism.

The respiratory phenomena do not exist in man and the aërial vertebrates only. They are found, of the most varied kinds, in all of the animal species, even in the lowest; these last, lacking true blood as well as a digestive tube, have particular juices introduced by absorption, the nutritive quality of which can develop only under the vivifying influence of atmospheric oxygen. It may here be added that the intervention of this gas is as indispensable to the plant as to the animal in all periods of life. The sap, analogous to the blood, cannot be sufficiently elaborated and become a really nourishing fluid except by the oxygen.

When a function is found in all living beings, it is logical to conclude that it represents one of the fundamental conditions of their existence. Respiration incontestably offers that character. Not only do all living species breathe at their different ages, but they cannot develop, or persist in their development, except by the accomplishment of that function. The most positive experiments have demonstrated that the cell of the plant and the cell of the animal breathe, one in the seed and the other in the egg in which it is organized, and that all development is arrested as soon as communication with the atmospheric air is prohibited. The seed absorbs oxygen from the air for the benefit of the young plant that it contains, fixes some traces of nitrogen, and at the same time exhales a considerable quantity of carbonic acid.

It was in a chicken's egg that respiration of the embryo was first recognized; when the surface of the egg was covered with an impervious coating of oil or varnish, the embryo failed to develop. Later it was proved that the egg containing a chick in the process of development also absorbs oxygen and exhales carbonic acid.

The life of mammals shows another form of the phenomenon: in them the fœtus, by reason of a certain union of its vascular apparatuses, draws from the blood of the mother the necessary oxygen which its pulmonary surface cannot yet supply. The villi of the placenta, plunged into the vascular sinuses of the uterus, effect a kind of respiration there.

THE RESPIRATORY APPARATUS.

The *object* of respiration is twofold, viz.: *to supply the oxygen* necessary for the numerous oxidation processes that are constantly occurring within the body, as well as to *remove the carbon dioxide* formed within the body. The most important organs for this purpose are the lungs or the gills, as the case may be, though it must never be entertained for a moment that they are the special seats for those combustion-processes whereby carbonic acid ensues as the final result. These processes occur in *all parts* of the body in the substance of the tissues. The lungs or the gills are merely the medium for the *exchange* of the two essential gases. For this interchange it becomes necessary that the atmospheric air should pass into them and that the changed air should be expelled from them.

In essence a lung or a gill is constructed of a thin membrane, whose one surface is exposed to the air or water,—depending upon the species of animal,—while on the other surface there is a network of blood-vessels, the separating membrane between the blood and aërating medium being the thin walls of the small blood-vessels and the fine membrane upon which they are distributed. The principle is always the same in all respiratory apparatuses; the difference between the simplest and most complicated ones is one of degree only.

In all animals in which, by reason of their complex structure, it becomes necessary to have special arrangements for the performance of the respiratory function it is found that the act is divided into two stages: (*a*) an *external respiration,* where the interchange is between the air or water on the one hand, and the circulating medium of blood on the other, as it passes through richly vascular skin, tracheæ, gills or lungs; (*b*) an *internal respiration*, which is an interchange between the blood or the lymph and the cells of the various tissues of the entire body.

Our consideration of the subject will confine us to the study of the human respiratory organs. The most important of the human apparatus are the lungs, which are contained within the closed chest, or thorax, and have no communication with the outside except through the avenue of the respiratory passages.

The *pulmonary apparatus* consists of: (1) the *air-passages*—nose, pharynx, larynx, trachea, and the bronchi, which communicate with the lungs; (2) the *lungs* with their immense number of small sacs, known as the air-vesicles; and (3) the *thorax.* The accessory muscles of respiration, when called into play, make the thorax act as a bellows, forcibly causing ingress and egress of air.

The Air-passages.—The very first portion of the respiratory passageway, the nose, is the organ of the special sense of smell and will be treated in detail when that subject is discussed; the anatomy of the pharynx has been previously noted when the alimentary canal was under attention. The *larynx* is placed at the upper part of the passage, being a dilatation of the trachea. It is the cartilaginous box which contains the structures concerned in the production of voice. It will be described later in connection with that function.

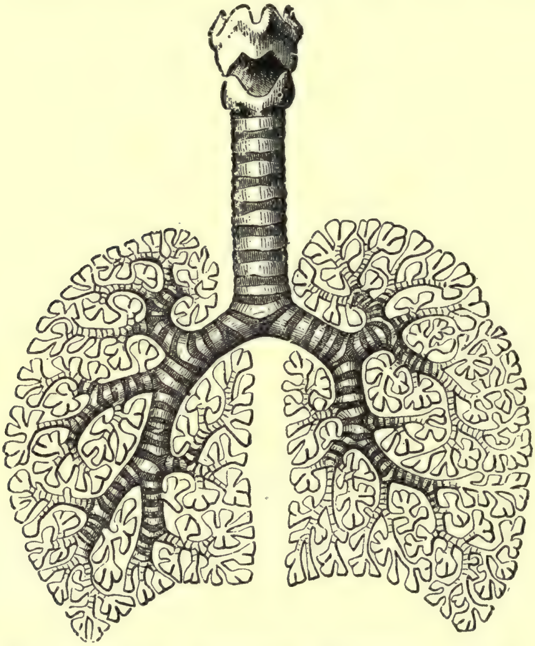

Fig. 111.—Human Respiratory Apparatus. (DUVAL.)

It shows the branching of the bronchia in the interior of the lungs.

The Trachea and Bronchi.—The trachea, or windpipe, is a combined membranous and cartilaginous cylindrical tube, flattened posteriorly. Commencing opposite the fifth cervical vertebra, it terminates by dividing into two bronchi opposite the third dorsal vertebra. Its length is about four inches, its breadth (less in the female than in the male), three-fourths of an inch. The bronchi diverge from the trachea to the lungs behind the great blood-vessels running from the base of the cardiac organ. The bronchus on the right side, about an inch in length, runs at a right angle to the root of the lung on a level with the fourth dorsal vertebra and posterior to the right pulmonary artery. The left bronchus, less in diameter than the right, but about twice its length, passes downward and outward beneath the arch of the aorta to the root of its corresponding lung. The bronchi and the trachea are composed of a series of cartilaginous rings lined with mucous membrane. The trachea and bronchi are encircled by the cartilaginous rings, which are not closed posteriorly except by a strong fibro-elastic membrane, and contain a layer of pale unstriped muscular fibers running in a transverse and longitudinal direction. The cartilaginous rings preserve the caliber of the trachea. The bronchial mucous membrane is smooth and its color is reddish

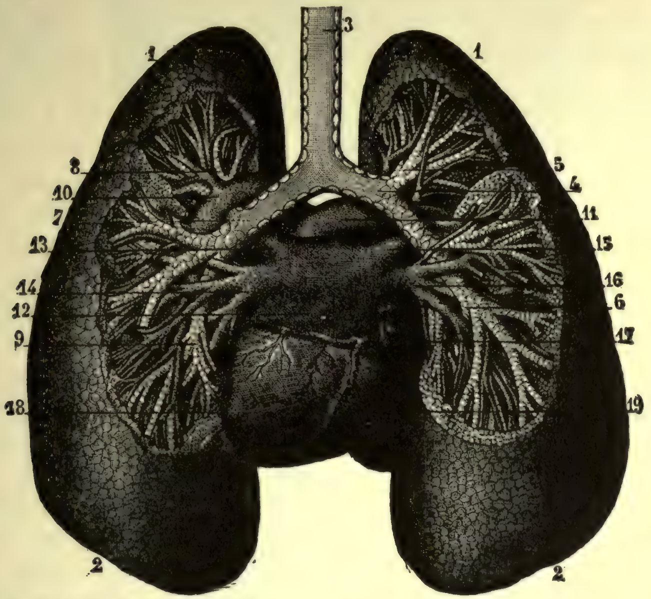

Fig. 112.—Bronchia and Lungs, Posterior View. (Sappey.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

1, 1, Summit of lungs. 2, 2, Base of lungs. 3, Trachea. 4, Right bronchus. 5, Division to upper lobe of lung. 6, Division to lower lobe. 7, Left bronchus. 8, Division to upper lobe. 9, Division to lower lobe. 10, Left branch of pulmonary artery. 11, Right branch. 12, Left auricle of heart. 13, Left superior pulmonary vein. 14, Left inferior pulmonary vein. 15, Right superior pulmonary vein. 16, Right inferior pulmonary vein. 17, Inferion vena cava. 18, Left ventricle of heart. 19, Right ventricle.

white. Its epithelium is of the ciliated columnar form. The vibratory movement of the cilia—being directed upward—removes dust from the lungs. Minute glands of the racemose variety, which open upon the surface, are found in the trachea and bronchi. The nerves supplying the trachea and lungs are the pneumogastric and the sympathetic.

The Lungs are in the thorax, one on each side, separated by the heart and the large blood-vessels. In the constantly changing diameters of the chest they accurately fill the chest which contains them. They are free, and attached only by their roots. They are closely invested with a serous membrane, the pleura. The root of the lung is placed near its middle internally, and consists of the bronchus, the pulmonary arteries and the veins, the blood-vessels of the bronchia, nerves, and lymphatics, all invested with a reflection of pleura. The right lung has its root behind the superior vena cava. The root of the left lung lies partly beneath the arch of and partly in front of the descending portion of the aorta. In the root of the right lung the bronchus is the highest; in the root of the left lung the pulmonary artery is the highest. The bronchi, before entering a depression at the root of the lungs, the hilus, subdivide, the right into three branches, the left into two, corresponding to the number of lobes in each lung. Each lung is conical, with a broad, concave crest resting on the diaphragm and a rounded apex standing above the level of the first rib into the neck. Its outer surface is convex and its inner surface is concave and faces the heart.

The weight and the capacity of the lungs vary according to many conditions. Their average weight is about two and one-half pounds and their total capacity three hundred cubic inches. Their long diameter is the greatest and deepest on the posterior surface. The right lung is shorter than the left, but wider and of somewhat greater bulk. The right lung has three lobes, of which the middle one is the smallest and the lowest one the largest. The left lung has two lobes, of which the lower is the larger. Between the lobes of the left lung in front there exists a large angular notch, corresponding with the position at which the impulse of the heart is felt against the walls of the chest.

Normal lung-tissue always shows a specific gravity less than that of water; consequently it will float when thrown into water. No other tissue does this. However, should lung-tissue in which consolidation has resulted from some disease or the lung-tissue from a child that has never breathed be thus tried, it will sink like other tissues. This water-test of the lungs is one of the medico-legal tests applied to ascertain whether a child found dead was "stillborn" or was a victim of infanticide.

The *substance* of the lung is of a light, porous, spongy texture, crepitating when handled because of the air contained in its tissue. Lung-tissue is very highly elastic; it completely collapses when removed from the thorax or if the thoracic walls be punctured so as to admit air from the outside into the pleural cavity.

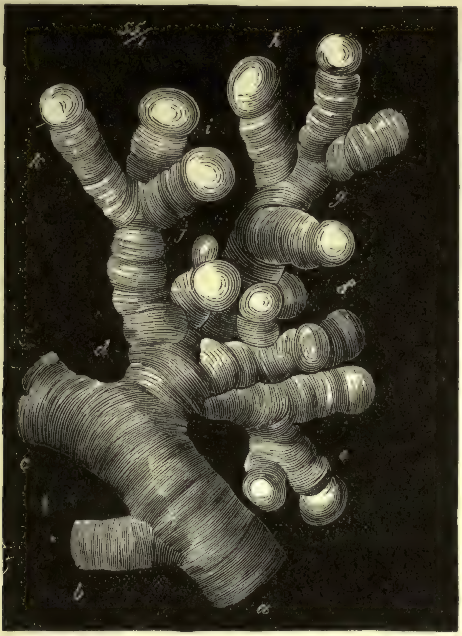

Fig. 113.—Mold of a Terminal Bronchus and a Group of Air-cells Moderately Distended by Injection, from the Human Subject. (Robin.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

In *color* the lungs are pinkish at birth, but of a mottled slate color in adult life. The dark-colored patches are produced by the presence of carbonaceous material that has been inhaled and deposited within the areolar tissue near the surface of the organ. The carbon particles are absorbed by the lymphatics, being carried into the lymphatic openings by the leucocytes.

Bronchi.—In structure the bronchi resemble the trachea. In the bronchi, however, there are unstriped muscular fibers forming the *muscularis mucosæ,* while the cartilaginous elements are scattered about equally in all parts of their circumference.

As the bronchi are traced in the lungs they divide into tubes of less diameter. These again subdivide into tubes growing smaller in a gradual manner. After a certain stage of division each tube is reduced to about one-fiftieth of an inch, and is denominated a bronchiole. These bronchioles then open into blind spaces called infundibula, which are lined with air-cells. Near the ending of the bronchiole with the infundibulum the former ciliated epithelium disappears and another variety of epithelium appears. This new variety of epithelium consists of small, flat, polygonal nucleated cells. This flat, thin epithelium also lies over the blood-vessels and even extends between the blood-vessels.

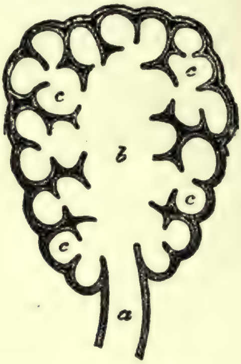

Fig. 114.—Termination of a Bronchus in an Alveolus.

a, Bronchiole. *b*, Cavity of the alveolus. *c*, Air-cells.

The alveoli of any group or series always communicate with one another to open by a common orifice into a terminal bronchus. In size they average roughly one one-hundredth of an inch in diameter. Form is given to the air-cells by the presence of a fine membrane of slightly fibrillated connective tissue which contains some corpuscles. This is closely surrounded by a great many fine, elastic fibers which give to the pulmonary parenchyma its characteristic elasticity. Some nonstriped muscular fibers are apparent in the connective tissue between the cells; in certain diseases these become abnormally developed. The number of alveoli has been estimated to be seven hundred and twenty-five millions, whose superficial area is sixty times greater than that of the body.

Within the alveolar walls exists a dense capillary network. They are placed more toward the inner side of the vesicle, being covered only by the thin lining of the air-sacs. So densely are they arranged that the spaces between the capillaries are even narrower than the diameter of the capillaries, which here are about one three-thousandth of an inch in diameter. In man between the folds of two adjacent air-cells there is found but a single layer of capillaries, while on the boundary line between two air-cells the course of the capillaries becomes so twisted that they project into the cavities of the alveoli. By these arrangements, and particularly since the intervening septa are so very thin and permeable, the exposure of the blood to the air becomes complete, as two sides of a capillary are thus exposed at the same time.

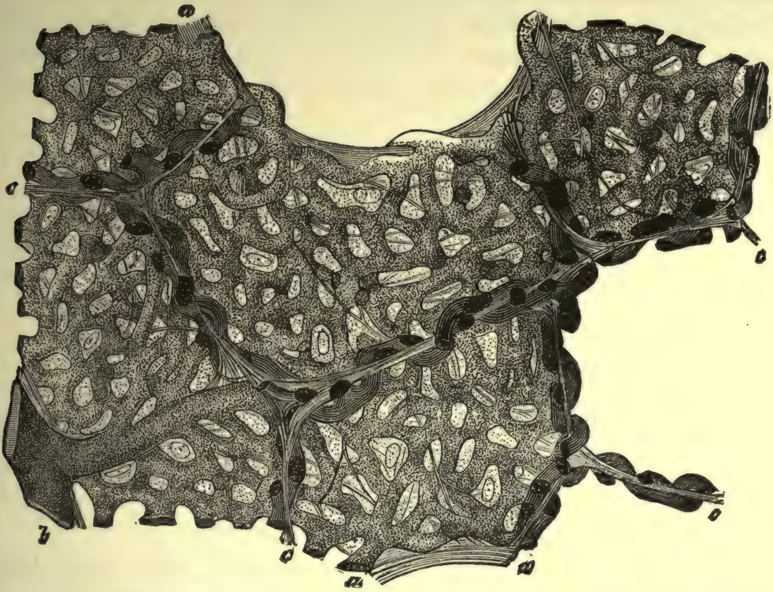

Fig. 115.—Section of the Parenchyma of the Human Lung, Injected Through the Pulmonary Artery. (Schulze.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

a, *a*, *c*, *c*, Walls of the air-cells. *b*, Small arterial branch.

Blood-supply.—The lungs receive a copious supply of blood from two sources: (1) the *pulmonary* and (2) the *bronchial arteries.* The bronchial arteries furnish nutriment for the lung-tissues. Six thousand liters of blood pass through the lungs in twenty-four hours,

The Pleura.—Each lung is enveloped by a serous membrane—the pleura—composed of two layers, one of which is closely adherent to the external surface of the lung; the other adheres to the inner surface of the chest-wall. These layers are designated *visceral* and *parietal.* The visceral pleura envelops the lung, while the parietal pleura lines the thoracic wall. The two become continuous with one another at the root of the lung.

By this means two large serous sacs are formed, each distinct and separate from the other. The pleural tissue is composed of a layer of fibrous tissue covered with endothelium. During health the two layers of the pleura are always in contact with one another, just enough fluid being present between them to allow of their gliding over one another with but very little friction during the accomplishment of the respiratory acts.

Lymphatics.—These are very numerous in lung-tissue and so arranged as to form several systems.

Nerves.—The nervous supply of the lungs is from the *anterior* and *posterior pulmonary plexuses* derived from the *vagus* and *sympathetic.* The nerves enter the lungs to follow the course of the bronchi and their branches and end in the unstriped muscle.

The function of the nonstriped muscular tissue of the lungs seems to be to offer a general resistance to increased pressure within the air-passages as may occur during forced expiration, as speaking, singing, blowing, etc. The vagus is the nerve which supplies motor fibers to these muscle-fibers.

MECHANISM OF RESPIRATION.

If respiration be suspended but a very short time there will soon be felt a lively anxiety due to the nonsatisfaction of an imperative need. This sensation of anxiety is produced by an internal sensation calling for need of breathing, it being promptly relieved by the proper introduction of air into the lungs. When the air inspired and retained becomes unfit for further oxidation, there arises another internal sensation which calls for the expulsion of that same air. Each respiratory movement is, therefore, preceded by a particular sensation which commands its execution.

These two movements constitute, by their regular succession, a *complete respiration,* the purpose of which is to maintain in the lungs regular currents which serve incessantly to renew the air altered by its contact with the blood. The mechanism for the accomplishment of respiration consists in an alternate dilatation and contraction of the chest by means of which air is drawn into or expelled from the lungs. These two acts have received the respective names: *inspiration* and *expiration.* As is known, the whole external surfaces of the lungs are in direct contact in an air-tight manner with the inner wall of the thorax, so that the lungs must be distended with every dilatation of the thoracic wall as well as be diminished in volume by every contraction of the same wall. The movements of the lungs are, therefore, for the most part, *passive,* being dependent upon the movements of the thoracic wall. This close approximation of lung to thoracic wall is dependent upon a state of elastic tension maintained within the lung, due to pressure exerted by the presence in the lung of residual air.

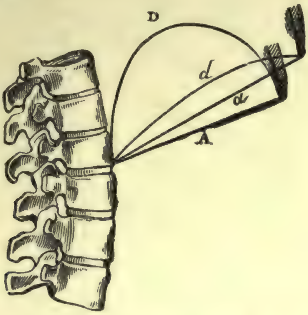

Fig. 116.—Diagrammatic Representation of the Action of the Diaphragm. (BECLARD.)

If *a* represents a plane extending in expiration from the sternum to the vertebra, and *D* the position of the diaphragm in inspiration, the plane *a* will move to *A*, while the diaphragm will descend to *d.*

From these data it becomes evident that all that is necessary for the production of inspiration is such a movement of the walls or the diaphragm, or the movement of the two synchronously, that the capacity of the interior should be increased. By reason of this increase there would be produced a temporary vacuum in the newly acquired space, or at least a great diminution of pressure within the lungs, so that atmospheric pressure upon the outside is greater than that within. Consequently there will be generated a current of air proceeding from the outside air through the larynx and trachea into the lungs, for the purpose of equalizing the pressure upon the inside and outside of the chest. The moment this point is reached there is cessation of the current. This incoming of the air constitutes the first of the two acts of respiration, namely: *inspiration.*

For the expulsion of the air that is no longer fit for oxidation it is evident that there must be a reverse movement of the thoracic walls whereby the chest-capacity is diminished. This act increases the pressure exerted by the contained air, with the result that as much of it is expelled along the usual avenues for its passage as is necessary to equalize the pressure upon the inside and outside of the chest. This outgoing of air constitutes the second act of respiration: *expiration*. The regular succession of these two alternating currents of air constitutes breathing, or *respiration*.

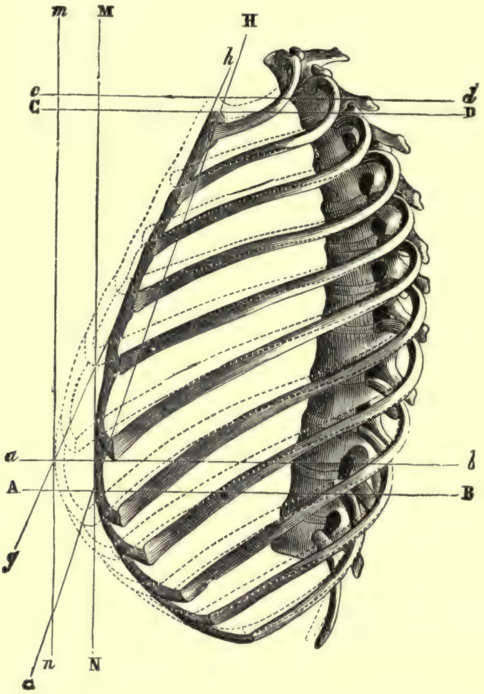

Fig. 117.—The Action of the Ribs in Man in Inspiration. (BECLARD.)

The shaded parts represent the positions of the ribs in repose. The line *A-B* represents a horizontal plane passing through the sternal extremity of the seventh rib; the line *C-D* represents a horizontal plane touching the superior extremity of the sternum; the line *H-G* indicates the linear direction of the sternum. When the ribs are elevated as indicated by the dotted lines, the line *A-B* becomes the plane *a-b*, the line *C-D*, the line *c-d*, and the line *H-G* becomes the line *h-g*, the projection of the sternum being more marked inferiorly. The distance which separates the line *M-N* from the line *m-n* measures the increase in the antero-posterior diameter of the thorax.

Inspiration.—Inspiration has for its motive agents the diaphragm, the intercartilagenous part of internal intercostals, the long and short elevators of the ribs and the external intercostals. All of these muscles by their contraction directly affect the expansion of the chest. The diaphragm is, *par excellence,* the muscle of inspiration; the others do not contract very extensively except for the needs of labored or forced inspiration. The scaleni are concerned in women to aid inspiration of the superior costal type, which is peculiar to the sex.

When a person is devoid of strong emotions or is not engaged in work or exercise, the breathing is quiet and regular. It is then said to be of the *ordinary type* and is principally diaphragmatic in character.

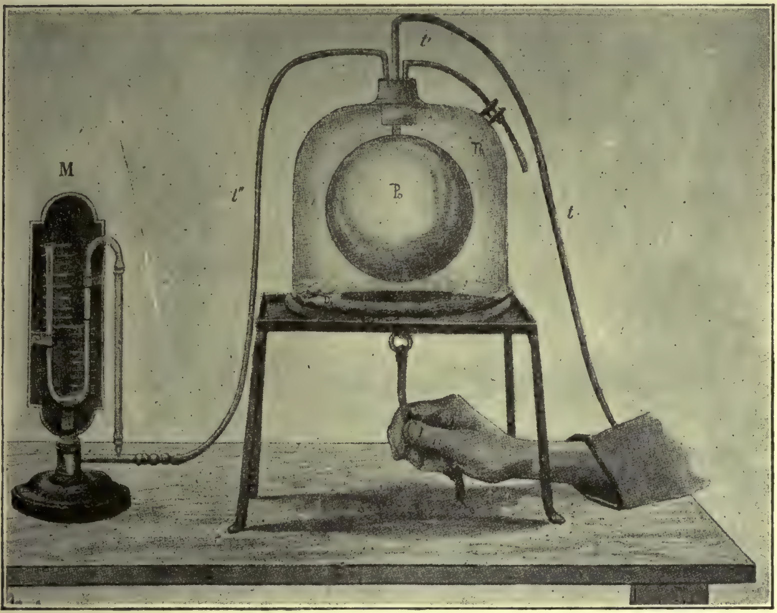

Fig. 118.—Schema of Respiratory Mechanism in Inspiration. (LAULANIÉ.) (See explanation, Fig. 119.)

When, however, the breathing is *extraordinary* in type, various other muscles are called into action.

The size of the chest-cavity is increased in (*a*) its *vertical diameter* as well as in (*b*) its lateral and antero-posterior diameters. The diameters are ascertained by means of calipers.

From the student's study of anatomy he knows that the diaphragm, when at rest and in a state of relaxation, presents the general form of a dome. The peak, or convexity, of the dome points upward. The student also knows that during contraction all muscles shorten their fibers, to which law the diaphragm is no exception. By its contraction the convexity of the dome is materially diminished, thereby producing more space and *increasing the vertical diameter*. This helps very materially to produce a vacuum into which air from outside of the body is pushed by atmospheric pressure. That is, there occurs inspiration.

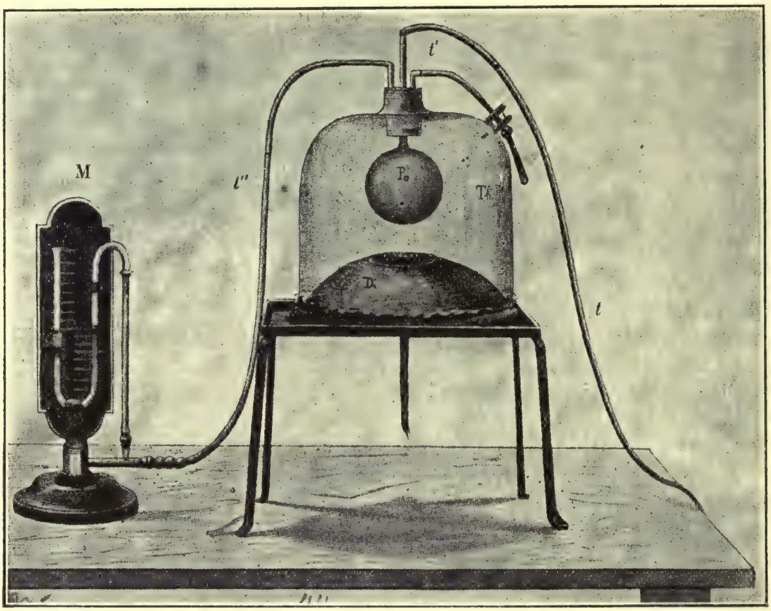

Fig. 119.—Schema of Respiratory Mechanism in Expiration. (Laulanié.)

Th, Thoracic cavity having at its base an elastic membrane, having a cord attached which makes traction in a vertical direction on the elastic membrane which represents the diaphragm. The bottle has a cork with three openings. ***t***, Represents the trachea opening into a rubber balloon. ***Po***, Representing a lung. ***t''***, Connecting the interior of the bottle with a mercurial manometer. **t'**, A tube with a clamp to be put on when the rubber lung has been inflated; it connects the space ***Th***, which represents the pleural cavity.

The diaphragm is supplied by the phrenic nerves.

In addition to the diaphragm, inspiration is aided by the raising of the ribs and sternum. Since the ribs are hinged posteriorly to the vertebral column, it is their lateral and anterior portions which possess the most motion; that is, their direction is slightly forward and upward.

In ascending, the ribs straighten upon the spinal column, and, instead of the lower ones in particular being so oblique, are now found to occupy a more nearly horizontal plane. This increases the antero-posterior diameter. At the same time that the ribs are raised they undergo a movement of rotation, by virtue of which they separate from the median line of the chest. It is this movement which produces an enlargement of the thorax in its lateral diameter at the same time the antero-posterior diameter is slightly increased.

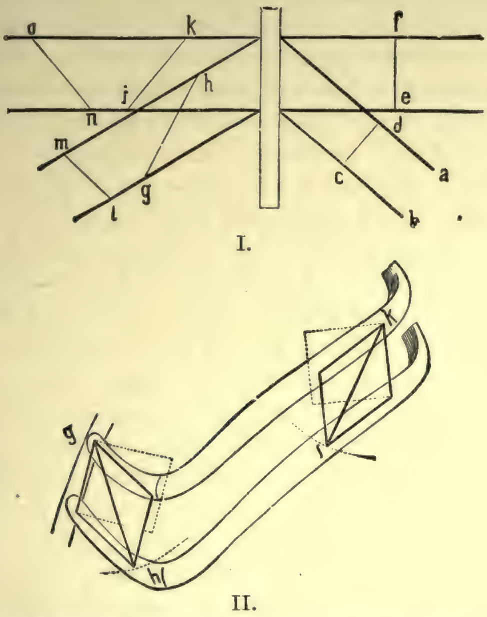

Fig. 120.—Schema of Action of Intercostal Muscles. (LANDOIS.)

I. When the rods *a* and *b* which represent the ribs are raised, the intercostal space must be widened (*e*, *f* — *c*, *d*). On the opposite side when the rods are raised the line *g*-*h* is shortened (*i*, *k* — *g*, *h*), the direction of the external intercostal, *l*-*m*, is lengthened (*l*, *m* — *o*, *n*) in the direction of the internal intercostals.

II. When the ribs are raised the intercartilaginei indicated by *g*-*h* and the external intercostals indicated by *l*-*k* are shortened. When the ribs are raised the position of the muscular fibers is indicated by the diagonals of the rhombs becoming shorter.

During *extraordinary* inspiration—as that caused by violent muscular exercise or when some pathological condition is present so that air finds its way into the chest only as the result of strong muscular effort—the other muscles are called into service: the scaleni, sterno-cleido mastoids, trapezii, lesser pectorals, posterior serrati, rhomboids, extensor muscles of vertebral column; also some of the laryngeal, palate and facial muscles.

Expiration.—Expiration, when it is effected with the aid of muscular powers, has as its causative agents the internal intercostals, the triangular sterni, the two oblique and transverse muscles of the abdomen, posterior inferior serratus and quadratus lumborum. It is in *complex* expiration—as crying, coughing, singing, expectoration, sneezing, etc.—that the preceding muscles enter into contraction. The abdominal muscles are the most powerful in the above-named group. In general, it may be said that any and all muscles concerned in the depression of the ribs belong to the expiratory set of muscles.

On the contrary, *ordinary* expiration can be affected by the mere relaxation of those factors concerned in the production of inspiration. During this relaxation the thoracic and abdominal walls, by reason of their elasticity, compress the air-distended lungs, and by so doing compel expiration. The lung-tissue itself helps to the extent of its own elasticity. The expenditure of that power and energy necessary to produce inspiration now becomes the expiratory exponent. During ordinary and tranquil breathing this elastic recoil of the stretched components is amply sufficient to expel the air from the lungs. Thus no muscular energy is required to perform expiration.

A normal lung is never able to contract to its fullest ability, since it is always distended to some extent by reason of its cohesive attraction with the interior of the chest-walls, as well as because of the presence of a certain proportion of air within the vesicles which exerts an expansive pressure.

It is interesting to note that, though the expiratory muscles be more numerous and powerful than the inspiratory ones, it is because the former are intended especially for *complex expiration;* that is to say, violent actions, since ordinary expiration is able to be effected by the mere elasticity of the parts. During expiration the lungs, which were dilated, return upon themselves, so that they let out a quantity of air nearly corresponding to that which entered at first. The lungs, which are seen to be entirely *passive* during inspiration, can participate *actively* in expiration, particularly in such complex acts as expectoration, coughing, etc,

MODES OF RESPIRATION.

There are various modes of respiration in man and in mammals which are usually classed under three principal types. In the *abdominal* type, characteristic among children, the ribs remain motionless and the respiratory action is revealed only by the movements of the abdominal wall; this becomes projecting during inspiration and sinks during expiration. In the *inferior costal* type, man's type, the respiratory movements take place especially at the level of the lower ribs, beginning with the seventh. Finally, in the *superior costal,* or *clavicular,* type, the respiratory movements are very manifest only about the upper ribs, especially the first, which are carried upward and forward. The clavicle also participates in this movement. This last type is the mode of respiration peculiar to women, who present it very early. The state of pregnancy, which would greatly interfere with the other types of respiration, does not hinder breathing very much in this last type, since the movements take place naturally at the upper part of the chest.

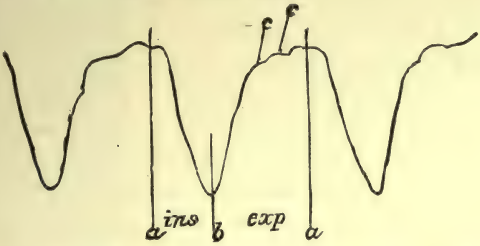

Fig. 121.—Tracing of a Respiratory Movement. (FOSTER.)

A whole respiratory movement is comprised between *a* and *a*, inspiration extending from *a* to *b* and expiration from *b* to *a*. The waves at *c* are caused by heart-beats.

Mays and Kellogg have found that pure-blooded Indian girls, who have never worn corsets, usually have the abdominal type and not the costal type of respiration. Fitz found little or no difference in the type of respiration of the two sexes when the corset had been removed.

The superior costal type is perfectly established in girls and women who have never worn a corset and this is probably due to heredity.

Among animals the abdominal type of respiration is found in the horse, the cat, the rabbit and the inferior costal type in the dog.

The Stethograph, or Pneumograph.—To gain an exact idea of the time occupied in the various phases of respiration it becomes necessary to obtain its curve, or *pneumatogram.* The apparatus for recording these respiratory movements is termed a *stethograph,* or *pneumograph.*

The simplest form of stethograph is that of Brondgeest. It consists of a brass saucer-shaped vessel covered with a double layer of

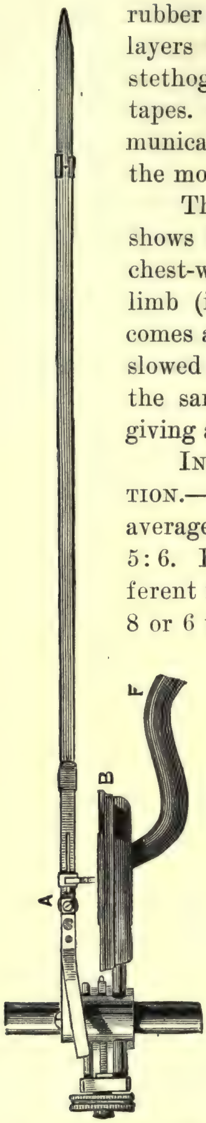

Fig. 122.—Marey's Tympanum and Lever. (Sanderson.)

A, Lever. *B*. Tympanum. *F*. Tube which communicates with cavity of the tympanum and connects with the tracheal cannula or the cardiograph.

rubber membrane. The air is forced in between the two layers until the external layer bulges outward. This stethograph is placed in position on the chest by means of tapes. The cavity of the saucer-shaped apparatus communicates with a recording tambour, which writes down the movements on a revolving smoked drum.

The resultant curve, known as the pneumatogram, shows that the acts of expansion and contraction of the chest-wall consume *nearly equal times*. The ascending limb (inspiration) is begun with moderate rapidity, becomes accelerated in the middle of its course, to be again slowed at its end. The descending limb (expiration) shows the same characteristics as to its construction, thereby giving a gradual fall to the curve.

Inspiration is Slightly Shorter than Expiration.—For all practical purposes it may be stated that the average respiratory *rhythm* is: Inspiration : expiration :: 5 : 6. However, it is known that various authors give different ratios, and in women, children, and old people 6 to 8 or 6 to 9 may be found. Immediately following expiration there is a *slight pause*.

Cases are rather rare in which the duration of inspiration and expiration are equal, or that of expiration shorter than inspiration. When the respiratory movements are studied as depicted on the pneumatogram, it is found that there is practically no pause between the end of inspiration and the beginning of expiration.

RESPIRATORY SOUNDS.

If a stethoscope is placed over a portion of a lung at some distance away from the trachea and larger bronchi, a sound will be heard the character of which is variously described as soft or sighing, resembling the rustling of leaves in a slight wind. The sound is heard during the whole of inspiration and is followed by a short expiratory sound. The inspiratory sound is three times the length of the expiratory. It must be remembered that the movements of inspiration are to those of expiration in point of time as 5 to 6, while the vesicular sound of inspiration is to that of expiration as 3 to 1. The cause of vesicular sound, according to one theory, is supposed to arise from the passing of air into and out of the alveoli and infundibula, the friction here generating a sound, aided by the sudden dilatation of the air-vesicles.

If now the stethoscope is placed over the trachea just above the suprasternal notch, two sounds are heard: one during inspiration, the other during expiration. They are not of equal length; the inspiratory is the longer. The quality of both sounds may be described as blowing, tubular, or bronchial. The expiratory part is more intense and frequently of higher pitch. This bronchial sound is produced by air in passing through the chink of the glottis, which is thrown into vibration, and imparts its motion to the columns of air in the trachea and bronchi.

In practical medicine it is inferred that, when the vesicular murmur is heard over any portion of the lung-tissue, this area being properly distended, the lung is in a healthy condition. If, however, the expiratory portion of it becomes loud and prolonged, it excites inquiry.

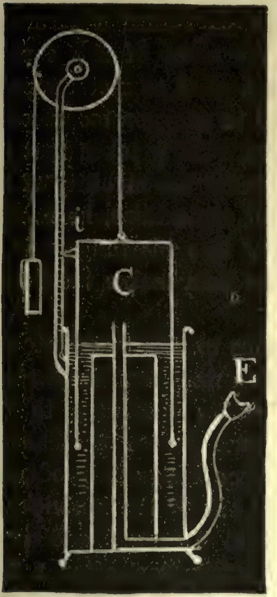

Fig. 123.—Spirometer. (Fredericque.)

E, Mouth-piece. *C*, Chamber to receive the air expired.

QUANTITY OF AIR BREATHED.

The determination of the volume of air necessary to the needs of human respiration is a problem that has received much attention. Because of a multitude of circumstances, both external as well as those that are proper to the individual himself, the figures representing the quantity of air that enters the lungs at each inspiration and the quantity that leaves them at each corresponding expiration can scarcely have more than an approximate value. Nevertheless, results which sufficiently agree to permit of establishing an *average* of the quantity of air put in circulation during each normal respiratory movement have been arrived at. It is very generally admitted that in an adult and healthy man, each inspiration introduces into the pulmonary apparatus about *20* cubic inches of air.

Among the numerous observers who have occupied themselves with the study of the quantity of air put into circulation, Herbst and Hutchinson, in particular, may be cited. The latter's *spirometer* is the instrument which has been most frequently used to secure data in experiments along this line. It represents essentially a gasometer. It is furnished with a fixed scale and a movable indicator; the latter follows the movements of the air receiver and indicates them on the graduated scale. The receiver dips into a reservoir filled with water and communicates with the chest of the experimenter by means of a rubber tube ending in a glass or metal funnel.

To measure the volume of air concerned in exaggerated respiration, the experimenter is made to stand up, care being taken that his chest is free from any restraint that would hinder the mobility of his chest. After several forceful inspirations and expirations, he inhales the greatest quantity of air that he can draw into his lungs. With the tube of the spirometer between his lips he then makes the fullest possible expiration.

By subjecting about two thousand persons to this test Hutchinson recognized that the quantity of air which a maximum inspiration and expiration can put into circulation varies according to the individual. It is 230 cubic inches for a man 5 feet 8 inches in stature. According to this observer, the prime factor in producing variance in pulmonary capacity is mainly the *size* of the individual.

For every inch of height from 5 feet to 6 feet, 8 additional cubic inches are given out by a forceful expiration after a full inspiration. *Vice versa,* for every inch below the 5-foot mark the capacity is diminished by the same amount.

The mobility of the thoracic walls has here a real influence. Persons with narrow chests are sometimes found who can dilate the thorax much more than those in whom the circumference of that part of the body is greater. With equal dimensions, the number indicated by the spirometer increases with the dilatability of the thorax.

The individual's capacity appears to be greatest in the period from the twenty-fifth to the fortieth year, showing a gradual increase until the latter mark is reached. From this point it begins to diminish, to become, in old age, less than it was even in youth.

Observers agree in admitting that, in woman, the maximum volume expired is perceptibly less than in man. The difference is usually represented by 50 cubic inches. Abdominal tumors, whatever their nature and whatever the organ affected, have the constant effect of diminishing the volume of air expired; pregnancy alone has not that consequence.

If a lung from an animal be thrown into a vessel of water, it floats. If it be forcibly submerged and then squeezed, bubbles of air will find their way to the water's surface. From this little experiment the student knows that, even though the lungs be collapsed, yet they contain a certain amount of air which is not very readily expelled. This is the air that is held within the confines of the small alveoli and that cannot very easily find its way through the small passageways opening into them. It follows, then, that all of the air in the lungs cannot possibly be changed during each respiration, and the amount that is changed bears a very close relationship to the type of respiration, whether it be forced or ordinary.

1. Tidal Air.—The volume of air that is introduced into the lungs during ordinary inspiration by an adult in good health is termed tidal air. *It is 20 to 30 cubic inches.*

The tidal air finds its way into and out of only the larger bronchi, where it comes in contact with the nearly stationary columns of air which extend through the smaller bronchial tubes. The oxygen finds its way into the blood flowing through the capillaries, while the carbonic acid makes its way into the larger bronchial tubes to be finally expelled from the body.

2. Complemental Air is the quantity of air which we are able to inspire with the greatest effort over and above that of ordinary breathing. The average is estimated by volume as *110 cubic inches.*

3. Reserved Air, or supplemental air, is the quantity of air *remaining* in the lungs after an ordinary expiration that would be expelled by the fullest effort. It is considered to be about *100 cubic inches.*

4. Residual Air is that which remains in the lungs after the fullest possible expiration and cannot be expelled by any voluntary effort. Its amount depends in great measure on the absolute size of the chest. Its volume is also *100 cubic inches.*

5. The Vital Capacity is the tidal, complemental, and reserved airs added together, and is *230 cubic inches.* It represents the amount of air which a person is able to expel from his lungs after the deepest possible inspiration. One-sixth of the air in the lungs is renewed at each ordinary respiration.

Professor Gad, of Prague, has constructed an instrument to measure the volume of the air expired and inspired. It is called an aeroplethysmograph. It consists of two boxes, one inside the other; the space between is filled with water. The inside mica box receives the air expired. At its posterior surface there is an axis which allows the anterior surface to elevate and depress itself. The movements of the mica box are recorded by a pen attached to it. The box itself is counterpoised by a weight. The instrument must be graduated, in order that one may determine the volume of inspired and expired air.

NUMBER OF RESPIRATIONS.

In an adult, the number of respirations per minute may vary from 16 to 24. It is usually stated that 4 pulse-beats occur during each respiration. The number is varied by the position of the body; thus, there may be counted 13 while recumbent, 19 in the sitting posture, and 22 respirations per minute while standing.

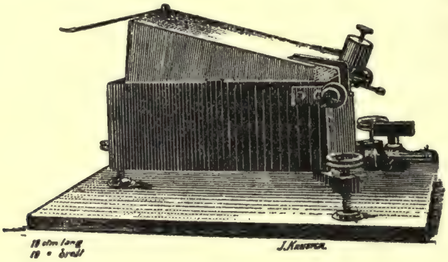

Fig. 124.—Gad's Aeroplethysmograph. (Krusich.)

During infancy and childhood the number of respirations is always greater than in the adult. Exercise temporarily increases respiration both as to number and to depth.

Every athlete knows of that condition popularly termed "second wind." At the beginning of severe exercise there is a marked dyspnœa which passes away after a short time, even though the exercise be uninterrupted. It is believed to be in a very great measure cardiac, due to a want of oxygen.

Pathological.—Respirations may be increased by reason of fever, pleurisy, pneumonia, some heart diseases, and anæmia. Diminution is occasioned by pressure upon the respiratory center in the medulla; this occurs in coma.

PRESSURE IN THE AIR-PASSAGES DURING RESPIRATION.

It has been previously stated that even after the deepest expiration the lungs are never completely collapsed. They are still "on the stretch" by reason of the elastic fibers contained in them.

The reason for the collapsing of the lungs when the chest is opened is that the pressure upon the pleural and alveolar surfaces is now equal, being that of the pressure of the atmosphere. The pressure of the residual air was sufficient to overcome the elasticity of the muscular fibers of the lungs. As long as the chest-wall was unopened the lungs contracted only until their elasticity was just balanced by the outward pressure of the contained air. In intra-uterine life, and in stillborn children who have never breathed, the lungs are completely collapsed (atelectasis). If the lungs be once inflated they never completely collapse so long as the thoracic walls be not pierced.

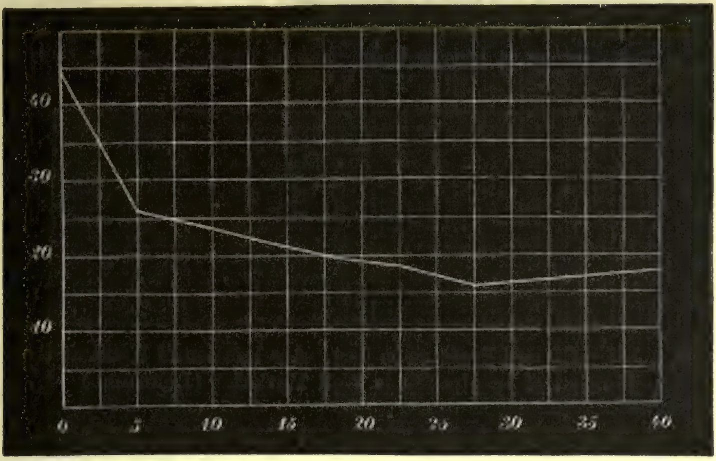

Fig. 125.—Number of Respirations by Man at Different Ages. (QUETELET.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Read from left to right.

When a manometer was attached to the trachea of an animal so that its respirations proceeded unchecked, every inspiration showed a negative pressure, every expiration a positive pressure. An observer placed a U-shaped manometer tube in one of his nostrils, closed his mouth, let the other nostril open, and then respired quietly. During every inspiration there was a negative pressure of

1 millimeter of mercury, during expiration a positive pressure of from 2 to 3 millimeters.

Forced respirations produce great variations from the above figures. The greatest negative pressure averaged — 57 millimeters of mercury during inspiration; the maximum positive pressure during expiration averaged + 87 millimeters.

The greater part of the force exerted in deep inspiration is used in overcoming the resistance offered by the elasticity of the lungs, the raising of the weight of the chest, and depressing the abdominal contents. These resisting forces acting during expiration aid the expiratory muscles; from this it follows that the forces concerned in forced expiration are much greater than those of inspiration.

Expiration is longer and stronger than inspiration, but the sound of inspiration is longer than that of expiration.

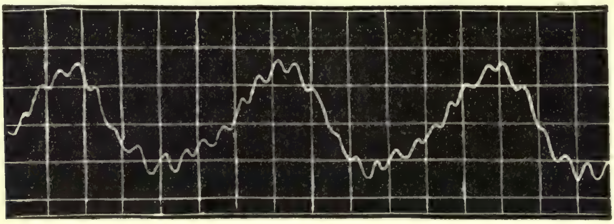

Fig. 126.—Carotid Pressure in Dog. Acceleration of Heart at the Moment of Inspiration is Well Marked. (Langlois.)

EFFECT OF RESPIRATION ON THE CIRCULATION.

When a kymographic tracing in an animal is taken there are seen rises and falls in it, due to the acts of respiration. Shortly after the commencement of an inspiration the arterial tension reaches its maximum, and immediately after an expiration it begins to fall, reaching its lowest level after the beginning of the subsequent inspiration.

The pulse is more rapid during an inspiration than during an expiration. I shall now inquire into the causes of these two changes: (1) those of blood-pressure, and (2) the increased frequency of the pulse.

The walls of the air-cells have an elastic force which is greater, the greater the distension.

This elastic force causes collapse of the lung and exerts a suction-like action on the contents of the chest. This negative pressure becomes greater and greater as the lungs are distended.

This negative pressure is called the intra-thoracic or intra-pleural, not intra-pulmonic, pressure, and is always less than the air-pressure. Intra-thoracic pressure is the pressure in the pleural cavity and mediastinum. The pressure necessary to counterbalance the elasticity of the lungs when they are quiescent in the pause of respiration is, in man, 7 millimeters of mercury, and when the lungs are fully distended it rises to 30 millimeters of mercury.

The pressure in the pleural cavity is less than an atmosphere; it is a negative pressure, and is due to the fact that the lungs are smaller than the thoracic cavity in which they lie.

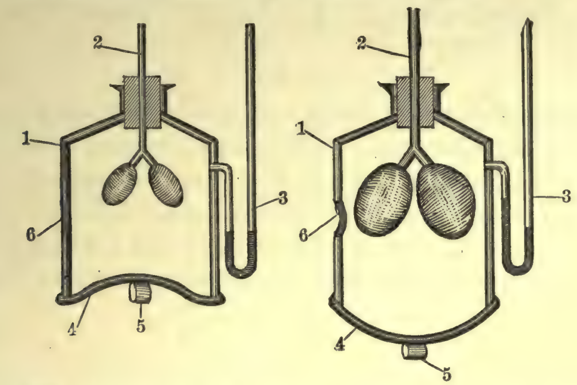

Fig. 127.—Apparatus to Illustrate Relations of Intra-thoracic and External Pressures. (After Beaunis.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

A glass bell-jar is provided with a light stopper, through which passes a branching glass tube fitted with a pair of elastic bags representing lungs. The bottom of the jar is closed by rubber membrane representing diaphragm. A mercury manometer indicates the difference in pressure within and without the bell-jar. In the left-hand figure it will be seen that these pressures are equal; in right (inspiration), the external pressure is considerably greater. At one part (6) an elastic membrane fills a hole in jar, representing an intercostal space.

It follows, then, that with a full inspiration the pressure exerted upon the cardiac organs in the chest is 30 millimeters less than that of the air-pressure of 760 millimeters of mercury.

When the waves of blood-pressure are compared with the curves of the movements of respiration or with the variations of intra-thoracic pressure, it is found that, while arterial tension rises during inspiration and falls during expiration, neither the rise nor the fall is exactly synchronous with either inspiration or expiration.

In inspiration, the flow of blood from the veins outside the chest is pressed towards the inside of the chest, because the air-pressure outside the chest exceeds the air-pressure within the chest. Hence a larger amount of blood enters the right auricle during inspiration. This being ejected by the right ventricle, the pulmonary capillaries, having less pressure externally, let the blood pass in larger quantity and the left ventricle forces out more blood into the aorta and the arterial blood-pressure rises. During expiration, the pressure on the heart and blood-vessels inside the chest returns to normal; hence the atmospheric pressure outside the chest does not drive the blood from the veins into the chest, as in inspiration, hence less blood goes into the right side of the heart, and, as the pulmonary vessels are also pressed upon, a less quantity of blood goes to the left ventricle and out into the aorta; hence a fall of blood-pressure.

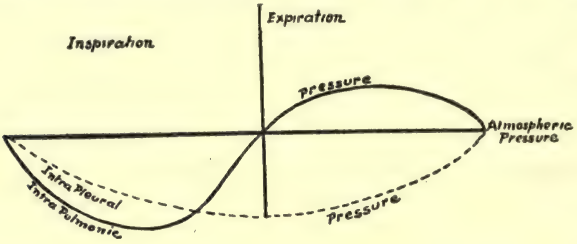

Fig. 128.

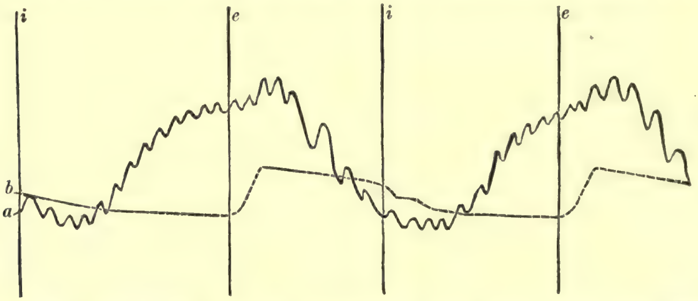

Fig. 129.—Comparison of Blood-Pressure Curve with Curve of Intra-thoracic Pressure. (M. Foster.)

(To be read from left to right.) *a* is the curve of blood-pressure with its respiratory undulations, the slower beats on the descent being very marked; *b* is the curve of the intra-thoracic pressure obtained by connecting one limb of a manometer with the pleural cavity. Inspiration begins at *i* and expiration at *e*. The intra-thoracic pressure rises very rapidly after the cessation of the inspiratory effort, and then slowly falls as the air issues from the chest; at the beginning of the inspiratory effort the fall becomes more rapid.

The pulmonary capillaries in the lungs contain more blood in inspiration because the inspiratory act tends to dilate them. The effect of the distension is to increase the flow of blood in the lungs, because the widened arterioles decrease the resistance to the flow. In expiration, the pulmonary capillaries are lessened in diameter, and the narrowing of the capillaries increases the resistance to the flow of blood. Hence it is the quantity of blood in the left ventricle which, during inspiration and expiration, elevates and depresses the blood-pressure.

Wherefore, on making a tracing of both the respiratory movements and the blood-pressure, it is discovered that the blood-pressure falls slightly at the beginning of inspiration, but rises during the rest of the movement. At the beginning of expiration the pressure continues to rise for a short time, and then falls during the rest of the act.

The arteries and veins are differently affected by the respiratory movements. According to Foster, the arch of the aorta has an inclination to expand, from the decrease of intra-pleural pressure in the thorax during inspiration, which temporarily retards the flow of blood and diminishes aortic pressure.

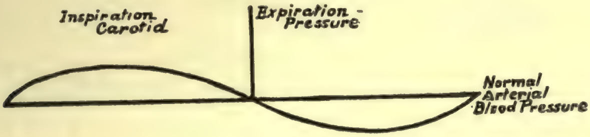

Fig. 130.

The aorta during expiration tends to contract, because expiration increases the thoracic pressure outside the aortic arch, which temporarily increases the blood-pressure in the aorta. Hence in inspiration the arterial pressure temporarily diminishes. During expiration the arterial pressure temporarily increases.

The blood-vessels of the lungs enlarge during inspiration and thus become more distended with blood, and thus retain for a while a certain quantity of blood in the lungs and thus diminish the amount falling into the left auricle. But this is only temporary, because the widening of the vessels would permit an increased flow of blood in the pulmonary vessels, due to diminished resistance of the dilated passages, and a contrary result would ensue.

Vice versa, the first effect of expiration would increase the flow in the left auricle, due to the additional quantity of blood driven on by the partial shrinking of the vessels of the lungs, followed by a more decided diminished flow caused by great resistance of the contracted pulmonary vessels. Hence inspiration first diminishes the flow of blood into the left auricle and necessarily in the left ventricle, but afterwards for the rest of inspiration, until the beginning of expiration, it increases the flow into the ventricle.

Vice versa, expiration temporarily, at first, increases and afterwards diminishes the flow of blood into the left ventricle.

The influence of thoracic negative pressure during inspiration and the return in a positive direction during expiration will have more effect on the pulmonary veins with their thin walls than on the thicker-walled pulmonary artery—that is, during inspiration there will be a diminution of pressure in the pulmonary veins greater than that in the pulmonary artery, and this will be an added influence in favoring the flow into the left ventricle. In expiration, a similar difference will be observed in the contrary direction. The left ventricle, from the increased flow of blood, will throw a larger amount of blood and the arterial pressure will rise.

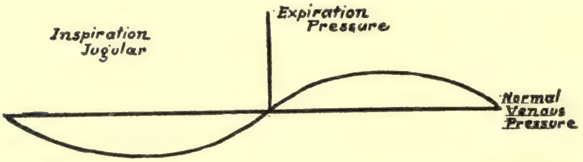

Fig. 131.

The respiratory movement on the vessels of the lungs at the beginning of inspiration will continue the lowering of the blood-pressure which was taking place during expiration, but afterwards will raise it. *Vice versa,* at the beginning of expiration it continues the rise of arterial pressure which was going on during inspiration, but afterwards lowers the tension in the arteries. Tigerstedt does not believe with De Jager, that changes in the capacity of the pulmonary vessels are the cause of the temporary fall of pressure at the beginning of inspiration and the temporary rise at the beginning of expiration. He found that cutting off half of the pulmonary circulation in an animal breathing naturally caused no fall in the systemic circulation. He believes that the variations in filling of the right heart with blood are the most powerful agents in producing temporary fall of pressure at the beginning of inspiration and a temporary rise at the beginning of expiration. The variations of blood-supply to the right auricle are due to the effect of respiratory movements on the veins outside the chest.

In studying the action of the respiratory movements on blood-pressure, we must remember that in the descent of the diaphragm in inspiration it presses upon the viscera of the abdomen and forces at first a quantity of blood along the vena cava inferior, but subsequently retards the ascent of the blood from the abdomen and the inferior extremities. In normal expiration, the diaphragm ascends and the viscera, not being so forcibly pressed upon, deliver less blood by the inferior vena cava to the heart.

During inspiration, the heart's frequency is greater than during expiration and the pulse-curve is somewhat different. If the vagi are divided, there is no difference in the pulse-rate during inspiration and expiration. Now, Hering has shown that distension of the lungs irritates the afferent nerves of the vagus center whose impulses inhibit the cardio-inhibitory centers and allow the heart to run faster. Another cause of the increased rapidity of the heart in inspiration is the spreading of impulses from the respiratory center to the vagus center, inhibiting its activity, and at the same time these radiations of impulses from the respiratory center are inhibiting the vasomotor center. The respiratory center, the vagus center, and the vasomotor center are connected by association fibers, and impulses can spread from the respiratory center over to the others.

Artificial Respiration.—When in artificial respiration air is driven into the lungs through a tracheal cannula with sufficient pressure, then the pulmonary circulation is arrested. Hence there is an opposite effect produced between artificial respiration and natural respiration as regards their influence upon the course of the blood.

The aspirating action of the thorax may suck air into a vein in surgical operations, which, on being transported to the right side of the heart, may block the pulmonary capillaries and cause a sudden death.

THE FUNCTION OF THE UNSTRIPED MUSCLE OF THE BRONCHIAL SYSTEM.

If a dog is curarized, the interior of a small bronchus is connected with a recording instrument (the chest having been opened), and if a vagus is divided, there will be a marked expansion of the bronchi. If the peripheral end of the vagus be stimulated, then a strong contraction of the bronchi will ensue. It is evident here that the smooth muscles of the bronchi are under the influence of the pneumogastrics. Broncho-dilator as well as broncho-constrictor fibers exist in the vagi going to the circular muscles of the bronchi. These effects could also be called out in a reflex manner. This explains asthmas due to reflex irritations transmitted to the centers of the vagi. Atropine and lobeline paralyze the vagus ending in the bronchial muscles. This explains their utility in spasmodic asthma.

VARIOUS FEATURES OF RESPIRATION.

Nasal Breathing.—During ordinary, quiet breathing most people breathe through the nostrils, keeping the mouth closed. This is very proper and there are certain advantages to be derived by so doing. Thus, in the passage of the air through the nostrils, whose walls are narrow and somewhat tortuous, the air is not only *warmed,* but rendered *moist* as well. By this means there is prevented the irritation occasioned by cold, dry air upon the lining mucous membrane. In addition, the smaller foreign particles are caught by the mucous lining and carried outward by the instrumentality of the ciliated epithelium.

Pathological.—Pulmonary œdema, which is a transudation of lymph into the pulmonary alveoli, occurs (1) when there is very great resistance to the blood-stream in the aorta and its branches; (2) when the pulmonary veins are occluded; (3) when the left ventricle, owing to mechanical injury, ceases to beat, while the right ventricle continues in its contraction.

Injection of muscarine rapidly produces pulmonary œdema by reason of increased pressure and slowing of the blood-stream in the pulmonary capillaries. The effects of this drug are counteracted by atropine.

Relation of Respiration to the Nervous System.—Movements of respiration are entirely dependent upon the nervous system. They are nicely balanced actions, performed by voluntary muscles under the guidance of a special presiding nerve-center, namely: the *respiratory center.* Through its influence the muscles of inspiration and expiration are kept working rhythmically and regularly, whether the individual be awake or sleeping. Co-ordinated impulses are constantly proceeding from the center to the muscles involved. However, the muscles being voluntary, they may be controlled momentarily by the will, and respiration be made to cease entirely for a minute or two. Soon the excess of carbon dioxide becomes so great that the will is overcome and respiration is begun again under the supervision of the respiratory center.

The Respiratory Center.—This center is located in the medulla oblongata, in the formatio reticularis, behind the superficial origin of the vagi and on both sides of the posterior aspect of the apex of the calamus scriptorius. Gad, by heated glass beads, destroyed parts of the medulla. He locates the respiration center in the lateral part

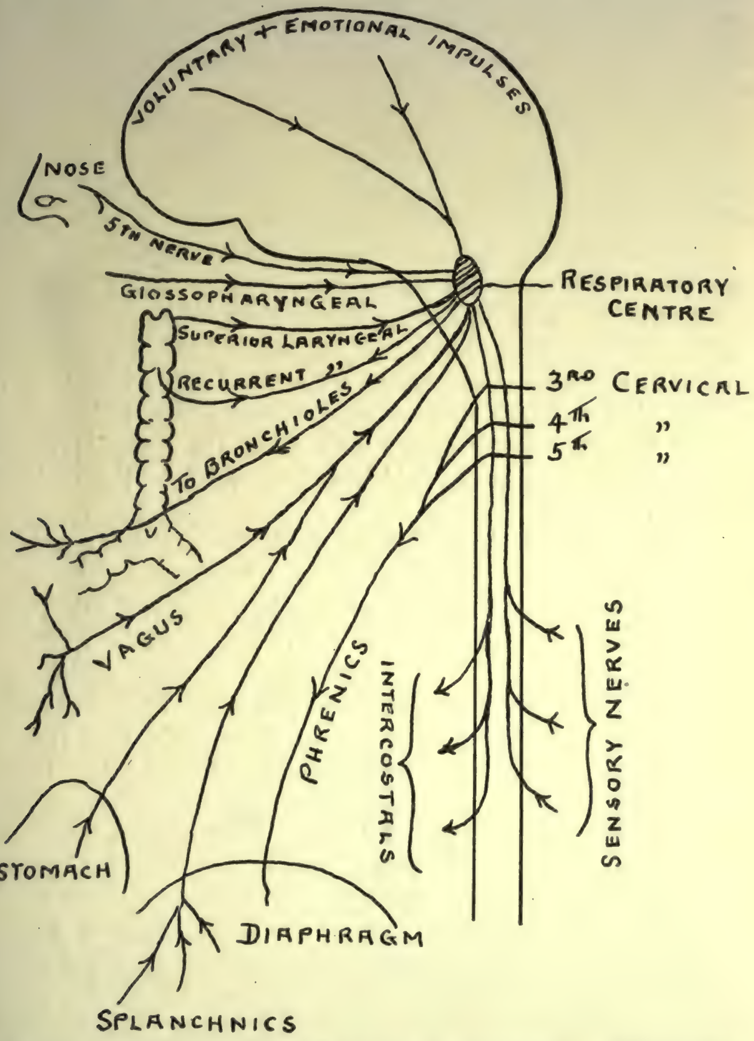
VOLUNTARY + EMOTIONAL IMPULSES
NOSE
5TH NERVE
GLOSSOPHARYNGEAL
SUPERIOR LARYNGEAL
RECURRENT "
TO BRONCHIOLES
RESPIRATORY CENTRE
3RD CERVICAL
4th "
5th "
VAGUS
PHRENICS
INTERCOSTALS
SENSORY NERVES
STOMACH
DIAPHRAGM
SPLANCHNICS

Fig. 131*a*.—The Respiratory Center and Its Connections. (HUTCHISON.)

of the formatio reticularis. Flourens, its discoverer, found that, when destroyed, respiration ceases at once and the animal dies. Hence he termed it "the vital knot." It is a bilateral center; that is, it has two functionally symmetrical halves, one on each side of the median raphé. If separated by means of a longitudinal incision, the respiratory movements continue symmetrically on both sides. Destruction of one-half of the medulla is attended with paralysis of respiration only on that side, seeming to prove that each half of the center is particularly concerned in the respiratory muscles of its own side.

During ordinary breathing impulses are sent from the respiratory center down the antero-lateral columns of the spinal cord to the cells of the anterior horns, then along the phrenics to the diaphragm and along the intercostal nerves to those muscles which elevate the ribs.

ACTION OF BRAIN IN FRONT OF THE RESPIRATION-CENTER.—If the tracts from the brain to the center of respiration with the vagi are divided, there ensues a want of rhythm in the respiratory movements. Here we have two afferent tracts removed, one in front, from the brain, the other by the vagi. Martin and Booker found that irritation of the mid-brain increased the number of the respirations and produced inspiratory arrest. Lewandowsky holds that the posterior corpora quadrigemina have a center which actively inhibits the center of inspiration.

While it seems to be undisputed that the principal respiratory center lies in the medulla and that upon it depends the rhythm of the respiratory movements, yet there have been found other supposed *subordinate* centers located in the cord. These, however, do not exist.

The cutaneous nerves also exercise some effect upon respiration. The most marked influence is exerted by those of the face (trigeminus), abdomen, and chest. Both thermal and mechanical stimuli easily excite them.

Irritation of the trigeminus by surgical operation, as in the removal of the adenoids, has been shown by Drs. W. H. Good and Harland to inhibit the respiratory movements and the cardiac action. Hering has shown that inflation of the lungs causes a marked increase in the number of heart-beats. He believes that the sensory nerves of the lungs stand in the same relation to the cardio-inhibitory center as the nervous depressor does to the vasomotor center. That is, irritation of the sensory terminals in the lungs, by inflation, causes reflexly a loss of tonus in the cardio-inhibitory center and a resulting increment of heart-beats. Dr. Jackson, in a case of inhibition of the heart and of respiration from trigeminal irritation, resuscitated a patient by mouth-to-mouth inflation. Dr. W. H.

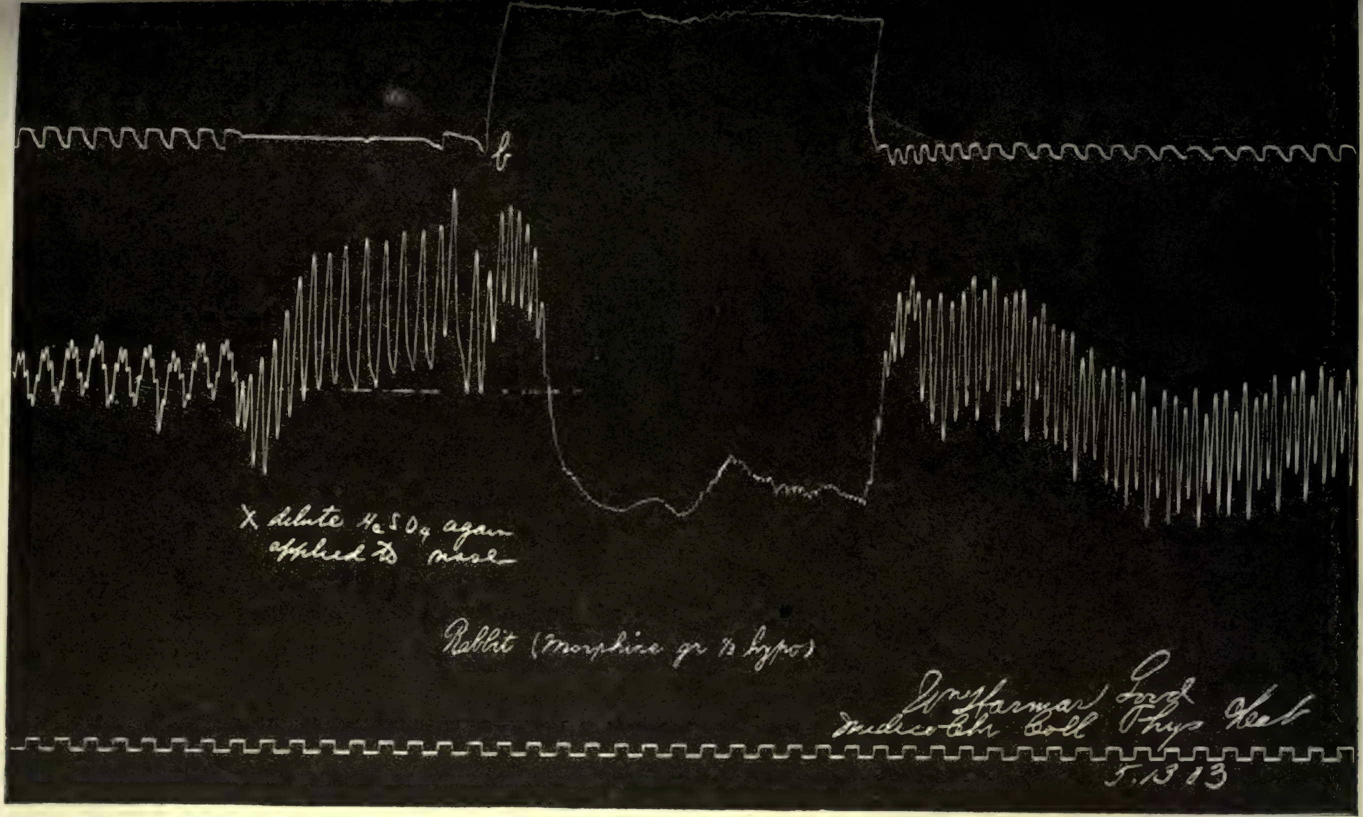

Fig. 132—Rabbit (morphine gr. $^1/_3$ injected hypo.). (Dr. W. H. Good.)

Upper line is the respiratory curve, with inflation of lungs at *b*. The middle line is the blood-pressure showing the cardiac pulsations. The lower line is the zero pressure and seconds marker. A few minutes before, the animal's nasal mucosa had been irritated with dilute sulphuric acid. The animal had not entirely recovered from the cardio-inhibition. At *X* dilute sulphuric acid was again applied to the nasal mucosa, the pulse immediately fell from 180 to 60 per minute At *b* the lungs were inflated (about 50 millimeters pressure), the pulse rapidly rose to 240 per minute, only to slow down again to about 84 per minute when the inflation ceased.

Good has tried artificial inflation on animals with excellent results, and proposes this procedure as a method of treatment in these cases of trigeminal inhibition.

Mechanical stimulation of the sensory nerves is sometimes resorted to by midwives. It is well known that to arouse a sluggish respiratory center they resort to slapping the buttocks of a newborn child.

During the act of deglutition there is a very necessary cessation of breathing for a short period. This is caused by stimulation of the central end of the glosso-pharyngeal nerve.

Section of the cord just below the medulla produces an arrest in the movements of not only the intercostals, but even the diaphragm. Section of one phrenic nerve paralyzes the corresponding half of the diaphragm; division of both nerves causes entire cessation of movement of the diaphragm. The phrenic nerves take an active part in the function of respiration. When these nerves are bared and irritated there is noticed a rapid movement of the abdomen produced by contraction of the diaphragm. The spasmodic movement is repeated at each irritation so long as the tissue of the nerve remains uninjured. If instead of mechanical, an electrical irritant be applied, the diaphragm is thrown into a state of tetanic contraction and produces death from asphyxia. As the irritability of the phrenic nerve remains a long time after death, it becomes easy to demonstrate these phenomena without causing any pain.

After section of the vagi the heart's movements become more rapid and the respirations slower. At the end of some minutes the nares dilate a little, inspiration is accompanied with a slight noise, an indefinite restlessness seems to seize upon the animal from head to foot; it moves about frequently, and raises and lowers the head as if there was a constriction of the throat. At length the anxiety of the animal disappears; it is calm and quiet; respiration is slow and the beats of the heart augment in frequency. Finally the animal dies from an affection of the lungs known as vagus pneumonia, due to removal of trophic vagi fibers of the lungs. The slow respiration is due to removal of afferent impulses in the section of vagi. For a time after the section the amounts of carbonic acid exhaled and of oxygen taken in remain the same, but finally they are much changed. The animals usually live seven days, but Pawlow has succeeded, by dividing one vagus and then waiting some time before dividing the next one, in keeping them alive.

Instead of tying or dividing the vagi, a galvanic current may be sent through them. There will follow disturbances of the vascular system, particularly the heart; so that death follows in a short time. If the central end of a divided vagus be irritated by a strong induction current, there is produced a strong degree of excitation in the medulla oblongata. It sends out impulses along motor nerves which arrest respiration in a state of inspiration, due to tetanus of the diaphragm. Stimulation of the central end of the superior laryngeal calls out an expiratory arrest. Each half of the respiratory district, termed a center, consists of two minor centers, which are in an alternate state of activity. The one center is *inspiratory;* the other, *expiratory.* Each one forms the motor central point for the acts of inspiration and expiration. The co-ordinated impulses proceed from these centers in the medulla along the nerves which supply the muscles of respiration and the associated muscles of the face, nose, and larynx.

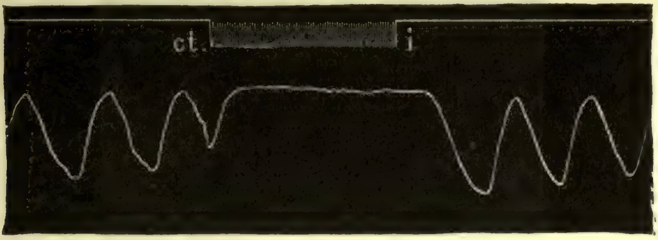

Fig. 133.—Arrest of Respiration in State of Expiration. (Hedon.)
By irritation of the central end of the vagus in a chloralized dog.

The activity of the *respiratory* center is excited by irritation of the sensory nerves, either cutaneous or pulmonary. It may also be stimulated by a strong excitation of the nerves which convey pain ducing dyspnœa; diminution of oxygen and the presence of heat are also noticeable factors. According to some observers, the acid substance formed in the blood when the muscles are greatly exercised also stimulates the inspiratory center.

The functions of the *expiratory* center, on the contrary, are stimulated by a strong excitation of the nerves which convey pain sensations.

The consensus of opinion among physiologists now seems to be in favor of considering the activities of the respiratory center as partly automatic, partly *reflex,* and that the vagus is the principal nerve concerned in the reflex activities.

The true causes of the rhythmic action of the centers of respiration are two: (1) the tension of carbonic acid on the respiration center (a chemical theory), and (2) irritation of the expiratory fibers in the vagus by distension of the lungs, and an irritation of the inspiratory fibers in the vagus in sucking the air out of the lungs (a mechanical theory.)

The vagi, in reference to the movements of respiration, according to F. H. Scott, must be regarded in the same light as the sensory nerves of the muscle. Without the vagi the respiratory muscular movements are excessive, and thus resemble the movements of an ataxic limb.

It is not the increase of oxygen which usually energizes the center of respiration. Zuntz has shown that a reduction of one-half the oxygen in the air inhaled had little effect upon the rate of respiration.

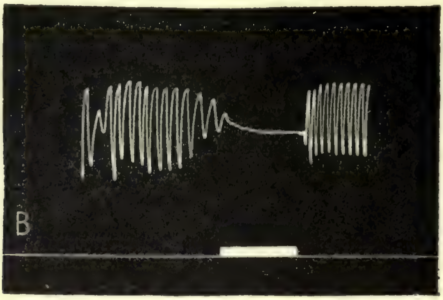

Fig. 134.—Strong Irritation of the Central End of the Divided Right Vagus of a Rabbit by an Induction Current. Arrest of Respiratory Movement in Inspiration. Read from left. (Gley.)

Haldane found that the center of respiration was not affected until the blood had lost one-third of its oxygen. When the tension of oxygen falls below 13 per cent. of an atmosphere, then deficiency of oxygen stimulates the center of respiration, for the tension of carbon dioxide in the alveolus is then lower than normal.

Haldane and Priestly found that the smallest increment of pressure of carbonic acid (0.2 per cent.) in the inspired air is accompanied by an increase in ventilation of the lungs sufficient to keep the percentage of carbon dioxide constant in the air of the alveolus. The tension of carbon dioxide regulates the respiratory movements.

Muscular exercise is the cause of an increased production of carbon dioxide and its tension. Here the compensation is by an increase in the alveolar ventilation in proportion to the increase of carbonic acid. Hence the hyperpnœa seen in exercise can be explained by a response of the center of respiration to the rise of pressure of carbon dioxide in the blood. The gaseous composition of the blood going to the respiration center regulates in great part the respiratory movements. The regulation of the rate of alveolar ventilation normally depends upon the pressure of carbon dioxide in the center of respiration and gives a satisfactory explanation of the normal breathing (eupnœa), hyperpnœa and apnœa.

Hering and Breuer put animals in a state of apnœa by repeatedly filling the lung with air from a bellows. Then when the chest was greatly distended, the tracheal cannula was closed and the thorax kept in that position. The first movement with a distended chest was one of expiration. Then after the animal was again made apnœic by repeated insufflations, the air was sucked out of the chest, the tracheal cannula closed, and the chest kept in that position. The first movement to be made was one of inspiration. The act of inspiration inhibits the inspiration and calls out expiration, whilst the act of expiration inhibits expiration and calls out an inspiration.

Hering, Breuer and Head held that the vagus contained two kinds of afferent fibers to the center of respiration, one concerned in calling out expiration and the other in calling out inspiration.

Gad believes that only one kind of fiber is necessary to explain the results of Hering-Breuer. It may be assumed that the center of respiration steadily tends to discharge inspiratory impulses and this discharge of impulses is inhibited by an impulse in the vagus produced by the filling up of the lungs in the act of inspiration. Then, in the expiratory collapse of the lungs, this inhibition is removed and the proneness to inspiratory impulse by the respiration center again produces an inspiration. This view was also supported by the experiments of Lewandowsky, who found that inflation of the lungs is accompanied by an action current in the vagus, whilst in the sucking out of the lungs, or collapse in expiration, no action current was present. Alcock and Seemann by using the more sensitive capillary electrometer, found that inflation of the lungs produced a negative variation in the vagus. They also found in contradiction to Lewandowsky that sucking out of the lungs also produced in the vagus of the rabbit a negative variation. In the cat there was either a positive variation, or a short negative followed by a prolonged positive variation, lasting as long as the diminished pressure. On letting the air into the lungs, so as to restore the normal distension, a negative variation followed. They explain the difference by supposing that these results are the algebraic sum of

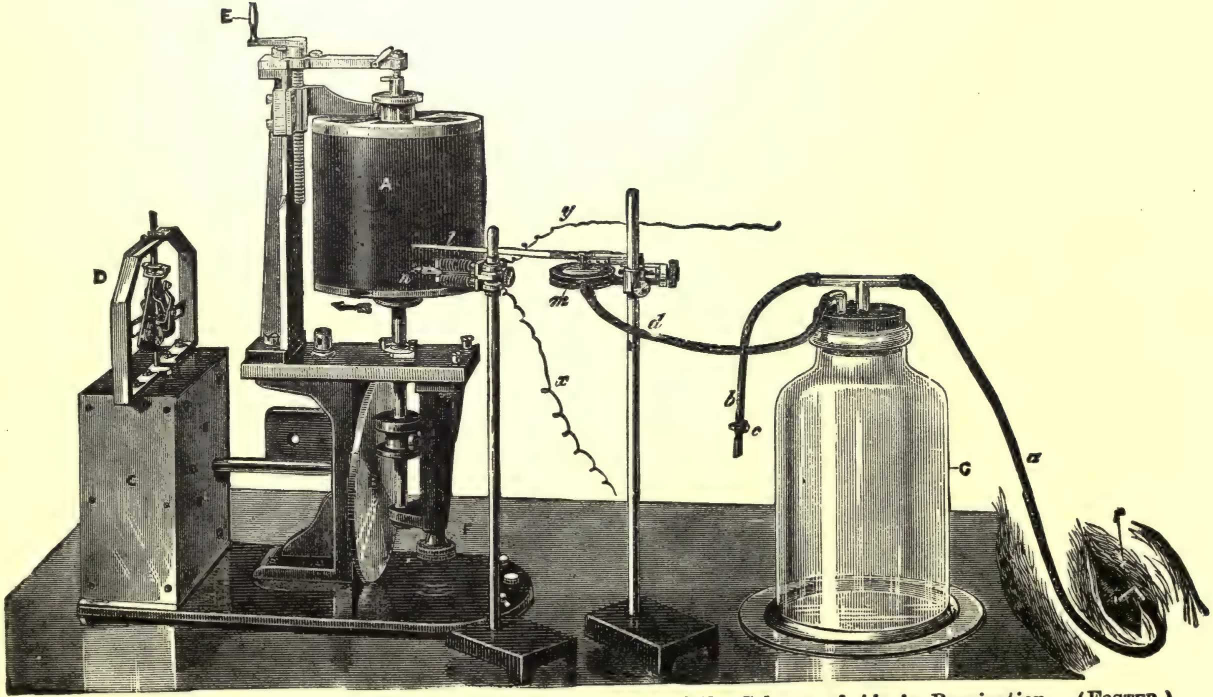

Fig. 135.—Apparatus for Taking Tracings of the Movements of the Column of Air in Respiration. (Foster.)

The recording apparatus shown is the ordinary cylinder recording apparatus. The cylinder *A*, covered with smoked paper, is, by means of the friction-plate *B*, put into revolution by the spring clockwork in *C* regulated by Foucault's regulator *D*. By means of the screw *E* the cylinder can be raised or lowered, and by means of the screw *F* its speed may be increased or diminished. The tracheotomy tube, *t*, fixed in the trachea of an animal is connected by India-rubber tubing, *a*, with a glass T-piece inserted into the large jar, *G*. From the other end of the T-piece proceeds a second piece of tubing, *b*, the end of which can be either closed or partially obstructed at pleasure by means of the screw-clamp, *c*. From the jar proceeds a third piece of tubing, *d*, connected with a Marey tambour, *m*, the lever, *l*, of which writes on the recording surface When the tube *b* is open the animal breathes freely through this, and the movements in the air of *G* and consequently in the tambour are slight. On closing the clamp *c* the animal breathes only the air contained in the jar, and the movements of the lever of the tambour become consequently much more marked. Below the lever is seen a small time-marker, *n*, connected with an electromagnet, the current through which coming from a battery by the wires *x* and *y* is made and broken by a clockwork, or metronome.

an excitation of one set of fibers and the diminution of a permanent excitation in another set.

Synchronous with the respiratory movements they noticed a variation of the current of demarcation of the vagus. The different facts lead to the original view of Hering-Breuer, that certain stimuli of inspiration induce expiration with inhibition of inspiration, whilst others in the collapse of the lungs inhibit expiration and induce inspiration.

Apnœa.—When a dog has frequent insufflations of air through a tracheal cannula by means of a bellows, there ensues an arrest of respiratory movements for a short time. Rosenthal believed this to be due to an excess of oxygen in the blood and that the respiration centers were not excited because of this excess in the tissues. Fredericque lately, by cross-circulation in the head of one dog with blood from another dog, has been able to produce apnœa which remains a long time if the other dog continues to receive exaggerated pulmonary insufflations. This apnœa is not due to an augmentation of the oxygen, but to a deficiency of tension of carbonic acid. The arrest that ensues in a dog by a frequent insufflation of hydrogen instead of oxygen is, according to Fredericque, due to irritation of the vagus fibers, which calls out an expiration-arrest and which is a simulated apnœa.

Thus, apnœa is produced by two factors, lessened tension of CO_2 and irritation of the terminals of the vagi. Mosso calls the diminished tension of CO_2 in the blood by the name of acapnia. The frequent ventilations of the lungs removes the CO_2 from the blood, and thus lowers the stimulation of the center of respiration. These rapid insufflations, also stimulating the ends of the vagi in the lungs, call out an inhibition of the respiration center. After section of the vagi it is difficult to produce apnœa.

Asphyxia.—In considering the phenomena of asphyxia, it is necessary to distinguish between rapid asphyxia, produced by complete obstruction to the entrance of air, and slow asphyxia, which is gradually established. The phenomena of asphyxia are divisible into three stages, which are easily observed in animals, especially in the dog.

In the *first stage,* called the stage of exaggerated breathing, hyperpnœa, the respiration is more rapid and deeper, due to the CO_2; then the phenomena of dyspnœa appear, the extraordinary muscles of inspiration and expiration are called into play, the abdominal muscles contract forcibly, the pupils are small. This stage lasts about a minute.

Second stage, convulsive stage. Here the inspiratory muscles lose their force, whilst the expiratory movements become more active; next all the muscles of the body, including the expiratory ones, become convulsed, due to the carbon dioxide stimulating the central nervous system. This stage lasts about a minute.

Third stage, or stage of exhaustion. This usually comes on suddenly, the carbon dioxide paralyzing the center of respiration; the pupils dilate, the eyelids do not close when the cornea is touched; a state of general calm ensues, which is in marked contrast with the previous agitation; consciousness is abolished; the animal lies motionless and seems dead; occasional inspiratory acts take place, then they become feebler and of a gasping character; finally, the nostrils dilate, the limbs of the animal are extended, opisthotonos ensues, the pulse disappears and death closes the scene. This state lasts about three minutes. This pulseless condition is properly denominated asphyxia. The phenomena of slow asphyxiation follows the same course, but less rapidly.

CIRCULATORY EFFECT OF ASPHYXIA.—The blood-pressure ascends during the first and second stages to about 160 millimeters of mercury and falls during the third stage to 20 millimeters and to zero. This rise of pressure is due to increase of carbon dioxide stimulating the vasoconstrictor centers, which causes the arterioles to contract, especially those in the splanchnic area. The immediate result is a filling of the venous system, which is assisted by the contraction of the inspiratory muscles of the trunk. The great veins are so distended that they spurt like arteries when cut. The blood-pressure falls mainly because the heart-muscles lose their irritability due to carbon dioxide and the slowing of the heart caused by the carbonic acid stimulating the cardio-inhibitory center. After death the right side of the heart is filled with blood and the left side is empty, or comparatively so. The heart is enlarged to nearly double its former size. The engorged veins fill the right side of the heart with blood, which dilates the heart because the internal pressure and the weakened tonus of the muscle by the carbon dioxide co-operate. The enfeebled right side of the heart is unable to expel its blood. At the same time the left side of the heart, having been also dilated by high arterial pressure, loses its power by the carbonic acid to contract, and the blood pools in the pulmonary vessels and the right side of the heart is filled with blood.

At first the rate of the heart is accelerated, but it soon becomes slower and more vigorous; the vagus center becoming excited by the carbon dioxide makes the beat of the heart slower.

During the third stage the pulsations of the heart become feebler and stop. After the respiratory movements have ceased the heart continues its action for a few seconds.

In slow asphyxia, as in death by membranous croup, there is a feeling of painful constriction around the larynx and sternum, yawns, gapings, and vain efforts to breathe, with dimness of sight, buzzing in ears, and vertigo, soon followed by loss of consciousness. The face and lips are tumefied and livid; the eyes watery and projecting; the conjunctiva injected; the jugular veins distended with blood; the nose, ears, hands, and feet have a violet color; the whole skin presents spots like bruises; the heart movements are uneven and intermittent, and grow weaker and weaker; finally the respiratory movements become less and less frequent, soon cease altogether, and almost at once the heart stops and the body is motionless in death.

As regards mammals, the age particularly affects the rapidity of death from suffocation. In fact, the newborn of this class of animals resist the suppression of respiration very much longer than adults. This accords with the instances of newborn infants which, having been found in pools of water, or even in water-closets, have been preserved alive, although the time passed since their immersion permitted but little hope of saving them. An adult cannot be submerged more than four minutes, and live.

ARTIFICIAL RESPIRATION IN ASPHYXIA.—In cases of suspended animation artificial respiration *must* be performed. Care should be taken first to remove any foreign bodies or froth from the mouth and nose. Draw forward the patient's tongue and keep it projecting beyond the teeth. Remove all tight clothing from about the neck and chest. For relieving asphyxia by dilating and compressing the chest so as to cause an exchange of gases there are several methods. Chief among these are Sylvester's, Marshall Hall's and Schaefer's.

In the Sylvester method the tongue is pulled forward to prevent any hindrance to the entrance of the air into the windpipe. Expansion of the chest is produced by drawing the arms from the sides of the body and then upward until they almost meet over the head. Bringing the arms down to the sides again, causing the elbows almost to meet over the pit of the stomach, produces contraction of the chest. The rate of elevation and depression of the arms should be about sixteen times per minute.

In the Marshall Hall method the person is placed flat upon his face, gentle intermittent pressure being made upon the back with one's hands. The body is then turned on the side and a little beyond, then upon the face again, and the same pressure continued as at first. The entire body must be worked simultaneously, the same number and frequency of these artificial processes of respiration being employed as in the Sylvester method.

Schaefer describes a new method of artificial respiration. It consists in laying the subject in the prone posture, preferably on the ground, with a thick, folded garment underneath the chest and epigastrium. The operator puts himself athwart or at the side of the subject, facing his head, and places his hands on each side over the lower part of the back (lowest ribs). He then slowly throws the weight of his body forward to bear upon his own arms and thus presses upon the thorax of the subject and forces air out of the lungs. This being effected, he gradually relaxes the pressure by bringing his own body up again to a more erect position, but without moving his hands. Efforts should be continued for a half hour before acknowledging failure to restore life.

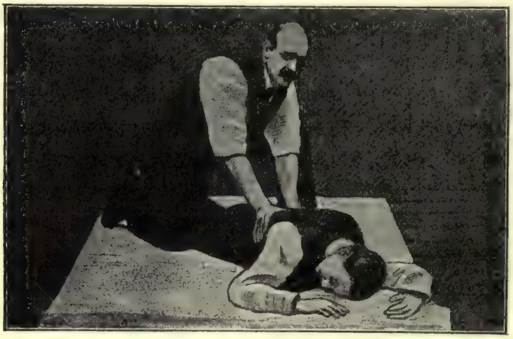

Fig. 136.—Shows the Position to be Adopted for Effecting Artificial Respiration in Cases of Drowning. (Schaefer, Howell.)

Ploman[1] has made many experiments upon men in a study of the various methods of artificial respiration. He used Gad's aeroplethysmograph to measure the volume of the ingoing and outgoing air. He found that the usual methods of Hall, of Howard, and of Sylvester produced a ventilation of the lungs much greater than is normally accomplished. The Schaefer method gave a ventilation a little greater than that of normal breathing. He believes the Sylvester method to be best for artificial respiration, especially when carried on with the modification of D'Jelitzin.

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[1] Skandinavisches Archiv, 1906.

D'Jelitzen proceeded as follows: At the same time that the arms are carried upward in the direction of the long axis of the body, the grip is transferred from the forearms to the elbows, so that the elbows strike against each other above the nape of the neck, or above the throat. In producing an expiration, the elbows are brought against the chest by the side of the sternum, and pressure made from before backwards.

In the Laborde method rhythmical traction of the tongue is made. This acts in a reflex way on the center of respiration.

In artificial respiration a bellows may be employed in a gentle manner so as not to rupture the lung.

Modified Respiratory Movements.—Since to breathe is to live, the modes of breathing indicate the modes of life. We see unfolded in a series of modifications of the respiratory act many of the sensations and emotions which man experiences in the course of his existence. His birth is announced by a cry, which seems the expression of a first pain; his death is revealed by a sigh, in which his last suffering is breathed out. In the number of his days there are very few devoted to laughter. There are more for sobs. Yawning often expresses his weariness; straining, the severity of his labor; sneezing, coughing, and expectoration are so many means that Nature employs to struggle against uncomfortable or painful sensations. All of these result from modifications of respiration. Hiccough is only manifested with their aid. Voice or speech, the supreme attribute of man, is only a particular mode of respiration.

SIGHING.—A large inspiration, slowly executed and followed by a rapid and sonorous expiration, constitutes the *sigh*. In normal conditions of respiration, in about every five or six inspirations there is one which is longer than the others; it is really a slight sigh. It is supposed that this longer inspiration supervenes whenever oxidation of blood needs to be accelerated. It takes place without participation of the will; in fact, it is one of those movements called *reflex*. The nervous center reacts spontaneously by reason of a painful impression received because of the accumulation of the venous blood in the right cavities of the heart. The unpleasant effect of sad emotions upon oxidation of the blood explains why sighs are given at such times. Their contagious nature is due entirely to sympathy.

THE YAWN differs from the sigh more by its mechanism than by its causes or effects. The needs of oxidation of blood call it forth in the same manner as the sigh is elicited. But, whereas the sigh *may* be voluntary, the yawn is always involuntary. It is not easy of imitation, since it is purely reflex; a person usually will not yawn if the need of doing it does not exist. Besides its relation to oxidation, it also expresses painful sensations in the stomach, hunger, or a feeling of torpor at the approach of sleep.

THE HICCOUGH cannot be compared with the acts connected with respiration, except by the noise accompanying it. It is a spasmodic contraction, abrupt and involuntary, of the diaphragm with coincident contraction of the glottis. The air, drawn rapidly into the chest by the convulsive contraction of the diaphragm, breaks upon the outstretched lips of the glottis, where is produced the sound characteristic of hiccough. The ordinary causes for this phenomena are engendered in the stomach by the too rapid introduction of alimentary substances, by alcoholic drinks and by nervous disturbances.

COUGHING usually arises from an irritation in the laryngeal passage; the irritating effect of the sensory filaments of the larynx reaches a certain intensity; there is then a deep inspiration, which is followed by a sudden and strong expiration.

Coughing can be produced voluntarily, but it is more often caused by reflex action, which it is generally impossible to resist. A cold draught on the skin or a tickling of the external auditory meatus will provoke a cough in some people.

LAUGHING AND SOBBING have this feature in common: they have their seat in the chest and face at the same time. They act especially upon the same muscle: the diaphragm. In the face they differ in this, that one has its own particular seat in the region of the eye, the other around the mouth. The same muscles, the same nerves, produce sobs and laughter. Their movements of inspiration and expiration are, however, accompanied by their own characteristic sounds.

SNORING is due to vibration of the soft palate.

CHEYNE-STOKES RESPIRATION.—This is a peculiar modification of the respiratory movements which is seen in certain pathological conditions, as in fatty heart, atheroma of the aorta, certain apoplexies, and in uræmia. It has even been noted in healthy children during sleep. It consists of respiratory pauses alternating with a series of respirations till a maximum depth and rapidity is reached; after this climax they gradually diminish till they end in another pause. Certain drugs—chloral is one—may cause Cheyne-Stokes respiration.

Cheyne-Stokes respiration rhythm is to the respiratory center what the Traube-Hering rhythm is to the vasomotor center. Both arise in their respective centers in the medulla oblongata.

The pause in Cheyne-Stokes respiration is somewhat less than half of the duration of the active period. During the pause the pupils are contracted and inactive; when respiration begins again they become dilated and sensitive to light. The eyeball is usually moved at the same time. Eyster has pointed out that with the Cheyne-Stokes respiration there are also rhythmic changes in arterial tension. (Traube-Hering waves.) He makes two groups of Cheyne-Stokes respirations. In one group the dyspnœa coincides with a lowering of arterial tension and a slow pulse-rate. In the other group the arterial tension and pulse both increase in the dyspnœa and fall in the apnœa. He found that intracranial increase of blood-pressure produces Cheyne-Stokes respiration. Douglas and Haldane have shown that Cheyne-Stokes respiration is produced by the periodic occurrence and disappearance of the (indirect) effects of want of oxygen on the respiratory center. The want of oxygen may be due to abnormal deficiency in the alveolar oxygen pressure, or it may be due to effects on the circulation of changes in the breathing, or to both causes combined.

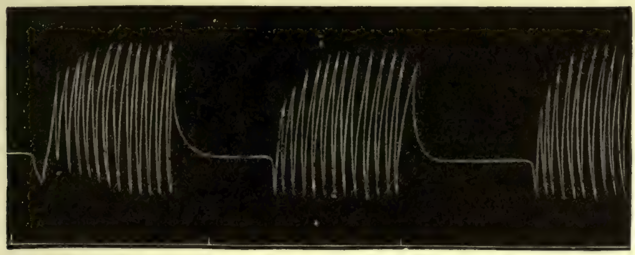


Fig. 137.—Cheyne-Stokes Respiration. (Waller.)

CHEMISTRY OF RESPIRATION.

Looked at from a chemical point of view, respiration presents the following phenomena: (1) absorption of oxygen; (2) exhalation of carbon dioxide; (3) release of a certain quantity of nitrogen; (4) exhalation of vapor of water.

It has been previously stated that at each normal respiration of atmospheric air but one-sixth of the air within the lungs is changed. Haldane states that it is evident that at the end of each expiration the air-passages up to the external openings of the nose and mouth are filled with alveolar air. At the next inspiration this alveolar air has to be drawn back into the alveoli before fresh air begins to enter the latter; hence the part of each inspiration corresponding to this "dead space"

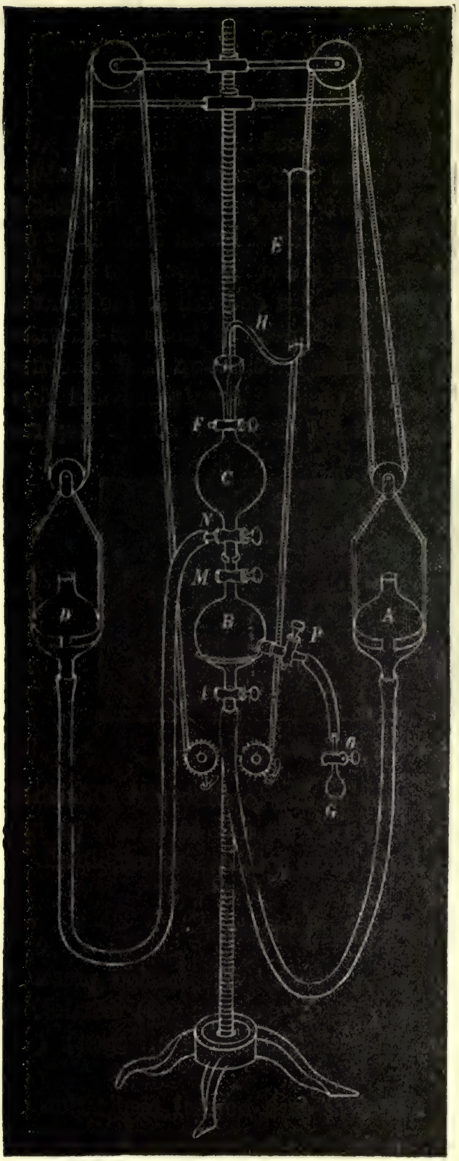


Fig. 138.—Ludwig's Mercurial Air Pump to Extract Blood Gases. (Lahousse.)

G, Receptacle for the blood.

must be ineffective except in so far as there may be a limited gaseous exchange between the air of the air-passages and the blood-supply to the mucous membrane of the air-passages. Thus, if the alveolar air contains 6 per cent. of CO_2, and the expired air 4 per cent., with a total volume of 600 cubic centimeters, the expired air may be regarded as made up of $600 \times \frac{4}{6} = 400$ cubic centimeters alveolar air and 200 cubic centimeters pure air. The effective dead space will be 200 cubic centimeters.

The capacity of the bronchi and upper air-passages will then be, according to Haldane, 200 cubic centimeters. Haldane believes that the air in the alveoli does not get there by the process of diffusion, but that the inspired air is drawn into the alveoli, which is a mixture of the air of the bronchi and which is derived from the upper air-passages, having, in proportion to the other parts of the air-passages, more atmospheric air. In expiration, the alveolar air partly leaves, having considerable CO_2, which air is diluted by the air in the bronchi containing more oxygen and with the atmospheric air holding still more oxygen.

Instruments to obtain alveolar air are known by the name of aerotonometers. Haldane and Priestly found that the normal per cent. of carbon dioxide in the alveolar air was almost constant in the same person, the average percentages were 5.62 to 6.28. The pressure of oxygen exhibited great variations. When the heart contracts (systole) it occupies less space in the thorax than it does during relaxation (diastole). Hence, air is sucked in or pushed outward through the open glottis by these movements.

A glance at the anatomy of lung-structure reveals the fact that the alveoli are surrounded by a dense network of capillaries. Some of the capillaries even project into the air-spaces. These conditions make more easy the processes of diffusion.

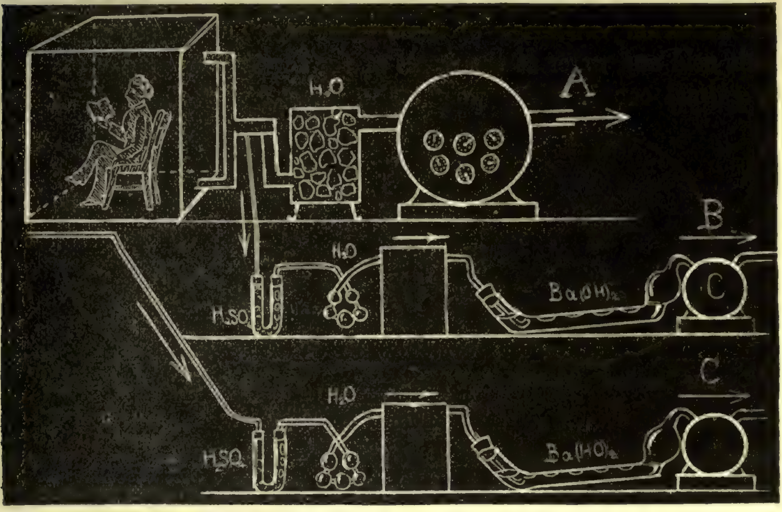
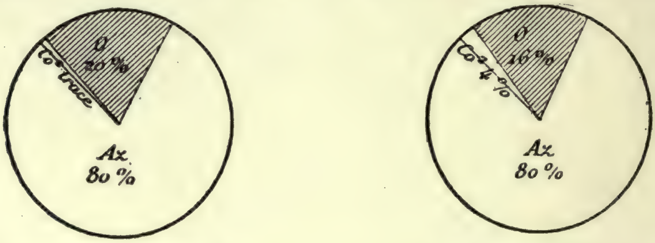


Fig. 139.—Schema of the Large Respiration Apparatus of Pettenkofer. (FREDERICQUE.)

A, Chief current of air measured by the meter, but not analyzed. B, Portion of air analyzed and coming from the chief current of air. C, Portion of air analyzed and coming from the surrounding air before it enters the apparatus.

Some of the oxygen from the respired air passes into the blood to form a loose chemical combination with the hæmoglobin of the red corpuscles: oxyhæmoglobin. This gives to the blood its red color, making it arterial. At the same time there is diffusion of carbonic acid from the impure, venous blood into the alveolar compartments. The oxyhæmoglobin of the blood is carried along by the blood-stream to the tissues (the real seats of respiration), where the oxygen becomes disengaged to unite with the tissue-cells. In the production of heat and energy it has united with the carbon of the tissues to form carbonic acid and with the hydrogen to form water. That which is not used up at once constitutes a reserve supply in the tissue to be used as occasion demands.

It has been ascertained that the quantity of oxygen absorbed within a given time is not found entirely in the carbonic acid exhaled by the animal during the same time. Consequently one can scarcely consider the oxygen as employed solely in burning carbon or in forming carbonic acid. Thus, animals draw from the surrounding atmospheric medium a quantity of free oxygen which attacks the ternary and quaternary materials of the organisms. These then exhale carbonic acid and water as the result of the respiratory combustion. As an animal can keep its weight the same during these combustive changes, it must be admitted that the carbon, hydrogen, and nitrogen thus lost must be unceasingly renewed by the materials it ingests and digests.



Air Inspired. Az—Nitrogen. **Air Expired. Az—Nitrogen.**

Fig. 140.—(Langlois.)

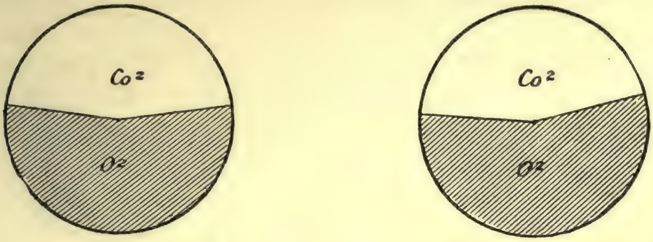
It is impossible to observe any constancy in the quantity of the products consumed or exhaled while searching into the amounts of oxygen absorbed and carbonic acid given off by man in a certain time. The chemical phenomena of respiration are, in fact, of such extreme changeableness, due to a variety of causes, that physiologists can scarcely know them all.

The expired air is richer in CO_2 than inspired. It contains 4.38 volumes per cent. of this gas, and consequently a hundred times more CO_2 than the air inspired.

The air expired is poorer in oxygen. It contains 16.03 volumes per cent. of this gas, which is about 4.78 volumes per cent. less than the inspired air. These figures show that the absorption or loss of oxygen is greater than the elimination of CO_2 This further substantiates the statement that all of the oxygen absorbed does not appear in the form of carbonic acid.

Seat of Oxidation.—It used to be held that the lungs were the seat of the metabolic processes. Afterwards the seat of these chemical changes was located in the tissues, the lungs playing but a small part. Bohr has shown that about one-third of the metabolic phenomena take place in the lung. He estimated the carbonic acid and oxygen in the blood of the right heart, and compared these quantities with those found in the blood of the left heart. He also measured the quantity of blood passing through the lungs in a given time. Knowing the amount of oxygen inhaled and the quantity of carbon dioxide exhaled, he found that the lungs used up about one-third of the oxygen and gave off one-third of the total carbon dioxide output.

The temperature of the air expired is greater than that of the air inspired, and is but a trifle lower than the body-temperature. Though the temperature of the surrounding atmosphere varies, that of the expired air remains nearly the same.



Proteids. $\frac{CO_2}{O_2}=0.85$

Normal Food Supply. $\frac{CO_2}{O_2}=0.80$

Fig. 141.—Variations of Respiratory Quotient According to Food Taken. (LANGLOIS.)

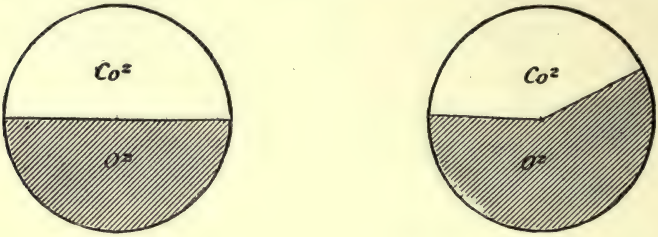
The *volume* of the air expired is greater than the volume of the air inspired, by reason of the increase in temperature and the contained watery vapor. If, however, it be dried and reduced to the same temperature as the inspired air, there will be a diminution of volume: about one-fiftieth.

The *respiratory quotient* is the relation between the volume of oxygen absorbed and the volume of carbonic acid eliminated. That is:—

The respiratory quotient $= \frac{\text{volume of } CO_2 \text{ given off}}{\text{volume of O absorbed}}$. Normally it is about $\frac{4.38}{4.78} = 0.9$.

This quotient varies, however, with the nature of the chemical composition of the foods ingested. With the carbohydrates the quotient approaches unity. The carbohydrates contain in their molecules enough oxygen to oxidize their hydrogen; all that remains for the inspired oxygen is to burn up the carbon. The fats and albumins, on the contrary, possess too little oxygen to burn all of the hydrogen and nitrogen they contain. Hence all of the oxygen is not found in the CO_2 eliminated, and the respiratory quotient falls to 0.75. On a mixed diet the quotient is intermediate between 0.9 and 0.75. In plants the respiratory quotient, especially in starchy ones, is equal to 1.0. In fatty seeds the respiratory quotient is 0.6 to 0.8.

Rate and Depth of Breathing on Respiration.—Pflüger has shown that the increased rate of respiration does not cause a greater exchange of CO_2 and O than slow breathing, excluding the effect of increased activity of the muscles of respiration.



Carbohydrates. $\frac{CO_2}{O_2}=1.$

Fats. $\frac{CO_2}{O_2}=0.70$

Fig. 142.—Variations of Respiratory Quotient According to the Food Taken. (LANGLOIS.)

Haldane and Priestly have shown that increasing the rate of respiration diminishes its depth; hence the percentage of CO_2 in alveolar air remains unaffected by the frequency.

Effect of External Temperature.—In the cold-blooded animal the temperature and the respiratory exchange vary with the external temperature. Warm-blooded animals in external cold increase and in external warmth decrease their respiratory exchange and the production of heat. They are greatly dependent upon the effect of the nervous system upon the tone of the muscles.

The response of warm-blooded animals to changes in temperature can be abolished by curare or section of the spinal cord. Here the muscles are not in tonus by the central nervous system.

Very high external temperature will increase respiratory exchange, for heat regulation is abolished and the tissues are unusually heated, as in high fevers.

Muscular activity augments the gaseous exchanges and so makes the respiratory quotient approach a unit. Other things being equal, man absorbs more oxygen and exhales more carbonic acid than a woman. The exchanges are increased during pregnancy.

During sleep the consumption of oxygen and the elimination of CO_2 diminish about 6 per cent. This decrease depends upon muscular and intellectual repose, darkness, etc. The cells of the tissues determine the amount of oxygen needed, and *not* an excess of the oxygen present. The intramolecular changes take place in the cells of the tissue, and not in the blood. The amount of water thrown off daily is about a pound; of oxygen taken in, about a pound and one-half; and of carbonic acid thrown off, a little more than a pound and a half.

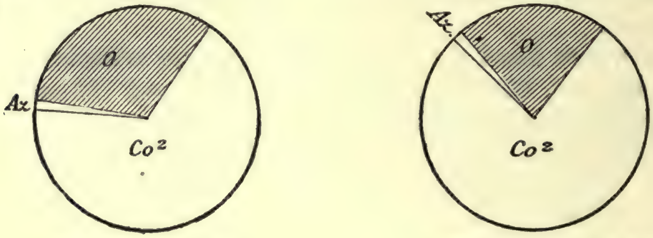
In human blood the average total gases are estimated to be, in round numbers, 60 volumes per cent, at 0° C. and 760 millimeters' pressure, made up as follows:—

	ARTERIAL BLOOD.	VENOUS BLOOD.
Oxygen	20	8 to 12
Nitrogen	1.4	1.4
Carbonic acid	39	46

The above table represents the average composition of the gases contained in man's blood.

A considerable attraction exists between the particles of solid, porous bodies and gases, whereby the latter are condensed within the pores of the solid bodies; that is, the gases are absorbed. Fluids also can absorb gases. One of the functions of the blood is to carry oxygen from the lungs to the tissues and carbon dioxide from the tissues back to the lungs for expulsion from the economy. These two gases, together with nitrogen, present themselves in two different states in the blood. The blood, a fluid, must very naturally absorb gases also. Hence one would expect to find O, CO_2, and N held in solution, and also that these gases should behave according to Dalton's law: the amount of gas dissolved in a liquid varies with the pressure of the gas; the higher the pressure, the greater the amount of gas dissolved. But oxygen held in the blood disregards Dalton's law, since its proportions in the blood in various parts of the body remain fairly constant no matter what the pressure. Hence, it owes its presence in and obeys laws dependent upon its being in the form of loose chemical combinations. If the oxygen were mainly held in solution, then the blood would give it up in a forming vacuum in direct proportion to the falling oxygen-pressure. That these conditions do not follow tends to establish the fact that the oxygen is held by some *chemical union.* Experimental physiologists also tell us that in their work they notice that very little O is given off in a forming vacuum until a very much reduced pressure is reached, when there is a sudden evolution of the gas, just as though it had been freed from some restraining influence. The restraint is now generally accepted to be the chemical union before mentioned.

Physiologists admit to-day that the major portion of the oxygen of the blood is contained in the red corpuscles, which are the special messengers for carrying it to the different tissues. When you compare the same amount of blood with an equal amount of water in regard to the absorption of oxygen both agitated in the air, it is found that blood absorbs more. The same amount of oxygen is absorbed whether you breathe air or oxygen. At a low partial pressure laked blood had a relative higher saturation than unlaked blood, for oxygen. The pressure of the CO_2 regulates the absorption of O by the blood, according to Bohr. When the O-pressure is low and CO_2-pressure high, the blood has a diminished capacity for oxygen. Haldane and Smith also found out that the oxygen capacity varies with the coloring power of the blood. The red corpuscles contain about 40 per cent of hæmoglobin. This coloring material is not the same as hæmoglobin in crystals for their capacity to absorb oxygen is different. A 40-per-cent. solution of hæmoglobin in crystals cannot be made. Bohr believes that there are four different varieties of hæmoglobin, which combine with



A.—Arterial blood per 100.
O........ 33
*CO*₂........ 64
N........ 3
100

V.—Venous blood per 100.
O........ 14
*CO*₂........ 83
N........ 3
100

Az is nitrogen.

Fig. 143.—Relative Proportion of Gases of Blood. (Langlois.)

different amounts of oxygen and have different "specific oxygen capacities," by which he means the ratio between the number of grams of iron and the number of cubic centimeters of oxygen present in a given volume of blood. The capacity of corpuscles for holding oxygen is nicely demonstrated by the following simple experiment: Serum, without corpuscles, is agitated in the presence of oxygen. The amount of oxygen absorbed is found to be less than half what would be taken up by the same amount of serum containing red corpuscles.

The oxygen, being preferably united with the corpuscles, is joined to them in a very unstable combination. The affinity is just strong enough to facilitate the conveyance of the gas in the circulatory system, yet not so strong but that it may attack the combustible materials of the tissues.

However, it must be kept in mind that *some* of the oxygen is contained in the *blood-plasma,* where it is in simple solution and obeys the laws of Dalton.

Ehrlich injected methylene blue into the vein during life. After death the blood was found to be blue in color, and the other tissues, especially the glandular, to be without color. Here the avidity of the tissues for oxygen has removed this from the methylene blue, which then becomes colorless. After a time the oxygen in the air is absorbed and methylene blue is again formed.

A curious phenomena of respiration in the tissues is that the exhalation of carbon dioxide does not directly depend upon the presence of oxygen. For fragments of tissue, when placed in an atmosphere absolutely deprived of oxygen, as in hydrogen, continue to produce carbonic acid. Engelmann and Pflüger hold that the protoplasm of the cells when exposed to oxygen has the power of storing it up in an intramolecular form. Respiration is not so simple as it appears to be: the oxygen absorbed is not immediately transformed into carbonic acid.

The cells of the tissues determine the amount of oxygen required and not the amount of oxygen available. Inhalations of pure oxygen do not augment the oxidation in the tissues.

The intracellular ferments change and oxidize the dead food-materials in the extracellular lymph which bathes them, just as has been shown that the yeast-cells break up the sugar surrounding them by their intracellular ferment, zymase, forming carbonic acid and alcohol. The animal tissues are like the yeast-cell, which obtains its oxygen, when deprived of it, by taking oxygen from that contained in the sugar, for the animal tissues are anaerobic, as they obtain the oxygen from the combined hæmoglobin. If living tissue is removed from the body and kept warm, moist, and aseptic, it breaks up by hydrolytic cleavage into simpler compounds, just as the tissue does when boiled with acids. This action is called autolysis, and is due to intracellular ferments. Pasteur holds that fermentation is a general phenomenon in metabolism. Schmiedeberg and others have shown a great number of oxidations taking place in the body which can only ensue through the intervention of intracellular ferments, which are called oxidases.

About one-third of the carbonic acid in the blood is found united with the globin of the red corpuscles, whilst the oxygen is combined with the iron-holding part of the blood.

Tissue Respiration.—The intake of oxygen and the outtake of carbonic acid is only a sort of preparatory phase of the respiration. The real respiration is in the tissues. As has been previously stated, the difference of pressure between the oxygen in the arterial blood and in the tissues easily explains the preponderance of oxygen within the tissues. The elevated temperature also aids the hæmoglobin in giving up its oxygen more freely. The tissues have no free oxygen, hence are always hungry for it. The pressure of the carbonic acid is greater in the tissues than in the liquids of the body.

The oxygen passes from hæmoglobin to plasma, then to lymph and from the lymph to the cells of the tissues. The carbon dioxide goes from the tissues to the lymph then to the plasma of the blood.

The pressure of oxygen in percentages of an atmosphere is as follows:—

External air	20-96
Alveolar air	16
Arterial blood	14
Tissues	0

In the dog, Fredericque gives the tension of carbonic acid in percentages of an atmosphere:—

Tissues	5 to 9
Lymph	4.4 to 4.9
Venous blood	3.8 to 5.4
Alveolar air	2.8
External air	.04

So often in the study of physiology the student's attention is called to the fact that the movements of the fluids of the body are always in the direction of higher to lower pressure. The explanation of the exchange of gases held in loose combination in the blood and those comprising the atmospheric air in the lungs is another interesting study of difference of pressure.

The exchange depends upon the law of "dissociation of gases," and is as follows: "Many gases form true chemical compounds with other bodies when the contact of these bodies is effected under such conditions that the partial pressure of the gases is high. The chemical compound formed under these conditions is broken up whenever the partial pressure is diminished, or when it reaches a certain minimum level, which varies with the nature of the bodies forming the compound. Thus, by alternately increasing and decreasing the partial pressure, a chemical compound of the gas may be formed and again broken up." (Landois.)

The CO_2 and the O in the blood form certain loose combinations which follow this law exactly. These gaseous compounds, as they circulate with the blood-stream, find conditions of high and low pressure enveloping them, whence they take up and give off their respective gases. As the pressures vary, so does the dissociation of the gases.

Thus, the oxygen-carrying elements of the blood, the hæmoglobin of the red corpuscles, as it reaches the pulmonary capillaries is poor in O. The air adjoining them in the pulmonary alveoli is rich with O. The hæmoglobin unites with the high-pressure O to form the loose compound oxyhæmoglobin. Later, the oxyhæmoglobin meets with tissues poor in oxygen and which need this element for their combustion. There is a dissociation from a higher to a lower pressure whereby the tissues receive their needed supply. The corpuscles receive replenishment again from the alveolar oxygen, and in this way the circle is completed.

On the other hand, the blood in contact with the body-tissues meets a high pressure of CO_2. By reason of which compounds are formed containing CO_2, in which form they reach the air-vesicles in the lungs. The inspired air contained within the air-vesicles has a much lower partial pressure of CO_2 than that contained in the venous blood coming from the tissues. Hence, the dissociation of the CO_2 from the blood to the vesicular air, finally to make its exit along the bronchioles, bronchi, trachea, etc., to the atmosphere. Bohr, of Copenhagen, believes the epithelial cells of the air-cells have the power to excrete carbonic acid and absorb oxygen independent of the differences in tension of the gases.

Bohr has shown that the vagi have an influence upon the intake of oxygen and the outtake of carbonic acid. In the turtle section of a vagus was followed by a considerable fall in the absorption of oxygen.

Irritation of the vagus increased the absorption of oxygen. In the warm-blooded animal irritation of the vagus increased the absorption of oxygen and the exhalation of carbon dioxide.

But how does the burning of carbon take place at the temperature of the body? Outside of the body the carbon will not be oxidized at the body temperature, but inside the tissues it is. This contradiction is explained by the presence of ferments, oxidases, which in the test tube certainly generate these oxidations, and probably also do so in the tissues.

In the living animal experiments have been made to determine the respiratory exchanges in different tissue. Chauveau and Kaufmann, in 1887, found by a comparison of the arterial blood going to the muscle elevating the upper lip of the horse and the venous blood coming from it, the following numbers:—

Quantity Per Minute and Per Kilogram of Muscle.

	O_2 absorbed	CO_2 given off	Respiratory Quotient
Repose	0.0068 gr.	0.0068 gr.	1
Work	0.140 gr.	0.245 gr.	1.75

They also made similar studies upon the parotid gland and obtained similar results. These experiments show the actual state of respiration in the tissues. The carbonic acid is formed in the tissues and thrown off by the lungs. Carl Vierordt, with a rubber band about his finger and a spectroscope for direct vision, saw the two bands in the spectrum of oxyhæmoglobin in the end of the finger gradually vanish and the single band of hæmoglobin appear. He found this to take place in two minutes, the time required for the tissues to consume the oxygen of the hæmoglobin in the blood retained at the end of the finger. This experiment demonstrated the avidity of the tissue for oxygen.

The blood itself has a very feeble oxidation when compared with other tissues. Zuntz cut the nerve in the leg of a dog and found that the exchange of gases was reduced. The lessening of oxygen used up and of carbonic acid given off was about the same in amount.

The question arises, How far are the carbon dioxide producing powers and oxygen absorbing powers of living tissue dependent upon one another? All the results of experiment show that the processes of tissue oxidation take place in more than one stage, and that the earlier stages are more readily accomplished than the final stage which leads to the production of free carbon dioxide.

To study tissue respiration it is incumbent to analyze the blood going to and leaving the organ and determine the amount of blood passing through the organ in a given time.

The British Committee, composed of Drs. Gotch, Barcroft, Starling and Brodie, have reported[2] as follows on The Metabolic Balance-sheet of Individual Tissues:—

1. The amount of oxygen taken up by the heart varied with the activity of the organ. Adrenalin, atropine and barium chloride increased the oxygen intake of the heart; stimulation of the vagus or administration of pilocarpine, chloroform or potassium chloride reduced the quantity of oxygen which the heart required.

2. When the chorda tympani was stimulated and saliva flowed the oxygen exchange was increased three or four fold.

3. *Pancreas.*—Intravenous injection of secretin in the dog caused a three-fold increase in the metabolism of the pancreas, coupled with a flow of pancreatic juice.

4. *Intestine.*—The metabolism was much increased during absorption, whether of water or peptone (dog).

5. *Kidney.*—Increase in the flow of urine induced by the injection of salts caused a three-fold increase in the oxygen consumption of the kidney, whether perfused through the renal portal vein or through the renal artery.

6. *Skeletal Muscle.*—They verified the co-efficient of oxidation as determined by Chauveau and Kaufmann. The production of lactic acid under anærobic conditions varied with the time and was increased by heat and stimulation.

They obtained some results of general application from the study of the metabolism of individual organs:

7. Increased vascularity does not of itself cause any change in the oxygen consumption. This has been shown in the heart, salivary glands and the kidney.

8. Increased vascularity is associated with increased production of carbonic acid in such a way as to suggest the conclusion that some product of the metabolic activity of the organ, probably not CO_2 itself, causes vascular dilatation during increased functional activity. This has been shown in the heart and salivary glands.

9. A comparison of the "co-efficient of oxidation" (the quantity of oxygen used up per gram of tissue per minute) varies for different organs when at rest. It is much higher for the glandular organs than for skeletal muscle.

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[2] British Medical Journal, Sept. 12, 1908.

10. From the results it would appear that the rôle of muscle as the great regulator of heat production is played as much in virtue of the relatively small amount of oxidation which takes place in it when at rest as the relatively great amount during activity.

Nitrogen.—The blood absorbs more nitrogen than the same volume of water would under the same condition. The increased absorption of nitrogen is dependent upon some physical conditions of the blood. These are the presence of hæmoglobin and oxygen.

Relation of CO_2 in the Blood.—Carbonic acid must be regarded, on the contrary, as one of the final products of the nutritive transmutations. When the very small proportion of this gas in ordinary atmospheric air and its considerable amount in expired air are considered, it is easy to be convinced that carbonic acid is indeed a product of the organism. The gas, therefore, comes from the tissues.

It is very generally admitted that the greater part of the carbonic acid is in a condition of chemical combination. The principal compound is bicarbonate of sodium, in the serum.

The sodium in the blood is the seat of a constant struggle between the carbonic and phosphoric acids to form a combination with it. When carbonic acid is in excess, there results sodium carbonate and monosodium phosphate. When the carbonic acid is diminished, the phosphoric acid acquires the greater part of the sodium, to form disodium phosphate. The proteids of the plasma and corpuscles can act as carriers of carbon dioxide. They can combine like weak acids with the alkalies of the blood, but a high pressure of CO_2 can displace them from the alkalies. Hæmoglobin can act like an acid and in a vacuum displace the CO_2 and unite with the alkali, but a high pressure of CO_2 can remove the hæmoglobin. Bohr even finds that hæmoglobin itself can absorb CO_2, which unites with its globulin part.

Effect of Distension of Lung on Heart-beat.—It has been found that, when the lung is distended, the heart beats faster; this increased action is caused by an irritation of the sensory nerves in the lungs, which, in a reflex manner, inhibits the cardio-inhibitory center and permits the heart to beat faster as the brake is taken off.

Dr. Da Costa, in his examination of twenty-four glass-blowers, found that in eleven the pulse ranged from 90 to 116 per minute. I have shown elsewhere that this is due to the irritation of the sensory fibers of the vagus by the great distension of the lungs, which also diminishes the irritability of the cardio-inhibitory center. The great lung-distension in glass-blowers occurs daily for years.

Now, it is well known that the inhibitory power of the vagus in man is very great, and its power varies in different individuals; this would explain why the thirteen other glass-blowers showed no habitual acceleration of the heart. As this performance is kept up many hours daily for a series of years, it is easy to conceive that the cardio-inhibitory power of the vagus center receives such a diminution of irritability so often that it would at length remain constantly weak.

Respiration of Different Gases.—The usual and normal medium inspired is ordinary atmospheric air, from which there is derived the needful supply of oxygen. The open atmosphere is a mixture of gases in the following approximate proportions:—

Atmosphere	Nitrogen, including argon, etc.	79.00	in 100 parts.
	Oxygen	20.96	
	Carbon dioxide	0.04	

Argon, NH_3, H_2O, and organic matter in small variable quantities.

Though the quantity of water in the air is marked,—over 1 per cent.,—it is not customary to reckon it in the gaseous constituents.

Some gases, as hydrogen and nitrogen, produce no specific effects from any toxic powers in themselves when they are breathed; they produce results simply because they exclude the proper supply of oxygen for the animal. On the other hand, gases such as carbon dioxide, carbon monoxide, nitrous oxide, and hydrogen sulphide, when respired in sufficient bulk, are absorbed and so produce specific, toxic effects. A third class of gases, such as ammonia and nitric oxide, are not respirable, because of their highly irritant action upon the respiratory apparatus. Spasm of the glottis is produced.

Carbon dioxide, when undiluted, is irrespirable by reason of the spasm of the glottis produced by it. Properly diluted it can be respired, but produces headache, dizziness, drowsiness, and dyspnœa by an action on the nervous system. *Nitrous oxide* acts directly upon the nervous system, partly by a special action and partly by producing an excess of CO_2 in the blood. *Nitrogen* and *hydrogen gases* produce their fatal effects by asphyxia, due to exclusion of the oxygen and thereby preventing oxygenation of the blood-corpuscles. Differing from these gases are the effects produced by inhalation of *carbon monoxide.* It was long known that this gas was poisonous, but it has only been within recent years that its mode of producing asphyxia has been learned. Instead of excluding the oxygen, it *displaces* the latter in the blood, forming a very stable compound with the hæmoglobin of the red corpuscles. It is interesting to note that the color of the blood after death from asphyxia from carbon monoxide is *cherry-red;* in other forms of asphyxia the blood is almost black. These occur from poisoning by coal-gas (especially where charcoal stoves are used in small rooms), the fumes of kilns and coke-fires, and from inhaling the air of coal-mines, especially after explosions.

Caissons and the Effect of Compressed Air.—In caissons men are able to support during some moments a pressure of five to ten atmospheres when they proceed with caution. If the pressure is too rapid, there is great danger. On decompression pains in the joints and muscles ensue, followed by paralysis, with deafness and vertigo. These symptoms are called "bends."

When an animal that resists a pressure of ten atmospheres dies instantly from a rapid change to ordinary pressure, the autopsy shows that the heart and large vessels are filled with bubbles of gas, especially of nitrogen. Under the influence of double or triple pressure the blood absorbs a double or triple proportion of air, especially the nitrogen. If the animal is submitted to a rapid diminution of pressure, the nitrogen, not being kept in solution in the blood, is disengaged in a gaseous state in the form of bubbles, which produce embolism in the capillaries of the brain, lungs, and heart, and arrest the circulation. To avoid the disengagement of bubbles of nitrogen it is necessary to let the atmospheric compression down in a very gradual manner. Operatives on leaving the tubes in which compressed air exists must remain a quarter to a half hour in the closed chambers, where the pressure is reduced little by little. The excess of gas absorbed is slowly eliminated by the lungs without producing an accident. Four atmospheres is about the amount that operatives can work in with safety. Every ten meters of depth in water roughly equals one atmosphere. By itself compressed oxygen is a toxic agent, for it lowers the output of carbonic acid and the temperature of the body. The cure for caisson-paralysis is recompression and slow decompression.

Hill and McLeod have shown that in compression air chambers there was no alteration of blood-pressure or pulse-rate, or in the diameter of the blood-vessels, or in the rate of the flow of blood. A rise of atmospheric pressure exercises no mechanical effect upon the circulation. Hill and McLeod have shown that the oxygen of the air compressed produces inflammation of the lungs, just like ether or any other irritant. This inflammation is produced in an hour or two with high pressures.

Bert has shown that air under the pressure of seventeen atmospheres, or pure oxygen at a pressure of three and a half atmospheres, will produce in animals convulsions resembling those of strychnia, and death ensues. It is the oxygen itself that kills, due to its being compressed.

Mal de Montagne, Rarefied Air.—All travelers who have climbed the Alps speak of the same troubles experienced by them at nearly the same altitude: a considerable diminution of appetite, a disgust for food, nausea and even vomiting, palpitations, headache, lassitude, sleepiness, and buzzing in the ears. This state is known as anoxyhæmia, or want of oxygen in the blood. Dyspnœa takes place not only because the air inspired contains oxygen in a given volume, but also because the dissolution of this gas in the blood is less easy under feeble pressure. Muscular work in the ascent also uses up considerable of the oxygen taken in. At 10 per cent. of an atmosphere there ensue restlessness and dyspnœa, and, at about 7 per cent., death. A partial pressure, like 7 per cent. of an atmosphere, corresponds to an altitude of 30,000 feet. Men in a balloon have ascended about 28,500 feet.

In respiration at low pressure Boycott and Haldane in their experiments could not support Mosso's theory that mountain sickness was due to lack of CO_2 (acapnia). The relief produced by the excess of CO_2 is due at least mainly to the artificial production of an abnormal hyperpnœa and consequent rise in the alveolar CO_2 pressure. The condition of the body then becomes one of hypercapnia, and indeed hypercapnia may be said to be already present at high altitudes with the addition of CO_2 to the inspired air, since the stimuli to the respiratory center are already in excess of normal.

Haldane and Poulton made experiments with a steel chamber in which the pressure of the air was reduced to that which prevails in the Alps. They found that the great hyperpnœa produced by a rapid fall in the oxygen pressure of the inspired or alveolar air is not due to a direct effect of want of oxygen on the respiratory center, but to that of preformed carbon dioxide present to start with in the blood, the action of this carbon dioxide being reinforced by that of acid or other products produced by the want of oxygen, so that the threshold pressure at which the carbon dioxide excites the center is lowered. If sufficient of the preformed carbon dioxide is first removed by forced breathing, want of oxygen has no exciting influence on the respiratory center and apnœa may be produced in the presence of want of oxygen.

The question arises, How do the inhabitants of high mountains escape the effects of a want of oxygen in the blood? To overcome this diminished absorption of oxygen Nature adapts itself by increasing the number of red corpuscles in the blood. Then the increased amount of hæmoglobin in the blood can take up more oxygen, and thus overcome the effects of a rarefied air.

Ventilation.—Let it suffice here to recall that the problem of ventilation consists in maintaining, in more or less closed spaces, the normal composition of the atmospheric air. Not only this, but to counteract the incessant modifications the respiration of man or of animals makes this medium undergo. For these purposes it is important that the ventilation should be very active.

It has been established that, for closed spaces intended to receive healthy persons, it suffices that the ventilation furnish 1,000 cubic feet of new air per person per hour. This is not sufficient for hospitals which contain sick persons, where more abundant and vitiated emanations are received by patients less fitted to react against their influence. Those hospitals which receive 3,000 cubic feet of fresh air for each sick person hourly are free from odor.

A healthy adult gives off about 0.6 cubic feet of carbonic acid per hour. If he be supplied with 1,000 cubic feet of fresh air per hour he will add 0.6 to the 0.4 cubic feet of carbonic acid it already contains. That is, he raises the percentage to .01.

Pharmacological.—The increase of pressure in the pulmonary circulation and a simultaneous decrease of arterial tension in the systemic circulation by amyl nitrite are due either to a contraction of the pulmonary vessels or to a weakness of the left ventricle, and as a consequence a backing up of blood in the left auricle. Nitroglycerine acts like nitrite of amyl. Aconite lowers the pressure in both the pulmonary and systemic circulations, due to a weakening of both sides of the heart. Ergot constantly causes a marked increase of pulmonary arterial tension, with a primary decrease of aortic pressure, hence is not useful in pulmonary hæmorrhage. Digitalis, strophanthin, and adrenal extract increase the tension in the systemic circulation, leaving the pressure in the pulmonary circulation unchanged. It is singular that the adrenal extract should so greatly affect the systemic pressure and not the pulmonary, whilst ergot acts reversely—augments the pulmonary pressure more than that of the aortic system. These facts show the independence of the pressure in the pulmonary vessels to the tension in vessels of the systemic circulation.[3]

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[3] Tigerstedt, Ergebnisse der Physiologie, 1903.

The blood-pressure in the pulmonary artery is about one-third to one-seventh that in the aorta.

As to the vasomotor nerves of the lungs, we do not know whether they have a tonus, or under what circumstances they are called into activity. It is natural to conclude, since pulmonary vasomotor nerves exist, that they are excited when the left heart has difficulty in emptying itself; in this case they could contract and diminish the afflux of blood to the left side of the heart.

Pathological Action.—The lungs are sixty times larger in surface area than that of the body; hence the blood oxidation should be perfect.

Inspiration opens the alveolar capillaries and the circulation of blood in them is accelerated. In mitral regurgitation there is a congestion of the blood-vessels in the alveoli.

The blood and lymph flow in the apices of the lungs are not much accelerated by inspiration, for there is a much less variation in respiratory pressure. The seat of tuberculosis is for this reason often in the apex of the lung.

Reflex contraction of the bronchioles resulting in asthma may be caused by polyps in the nose or by irritation from the stomach.

Corsets by interfering with the function of the abdominal muscles in the support of the liver and other abdominal viscera cause them to be dislocated downward (Glenard's disease).

The respiratory and vomiting centers are near neighbors in the medulla oblongata; hence dyspnœa by irritating the respiratory centers spreads impulses to the vomiting center.

The excessive use of tobacco, by depressing the respiratory center, may cause sighing respiration.

CHAPTER VIII

SECRETION.

INTERNAL SECRETION.

THE tissue-activity of the organism may be conveniently classed under three groups: (*a*) *muscular activity,* manifesting itself in heat and motion; (*b*) *nervous activity,* including all nervous acts, from sensation to reason; (*c*) *glandular activity,* which is the general function of epithelial and lymphoid tissues. It includes all those changes of metabolism whereby there follows, as a result of elaboration, a special mixture.

It is with the last of the three—glandular activity—that we are now to deal. However, the human economy being such a complex organism, it must be borne in mind that disturbance or lack of activity of one kind may have a very marked influence upon other metabolic functions. It is well known, especially among animal fanciers, what a great effect the removal of the ovaries and testicles may occasion in the development of other organs and in the general nutrition of the body. Proteid waste of increased proportion follows the removal of a considerable portion of renal tissue. The liver is most intimately connected with the metabolism of carbohydrates and proteids as well as those food-constituents which contain iron.

The gland-cells enjoy an essential rôle in secretion. These cells are applied upon the basement membrane of the glandular acini in such a fashion that each *cul-de-sac* is surrounded by a network of capillaries. Ludwig and Tomsa have shown that between the blood-capillaries and the acinus are found lymphatic spaces. The cells of the acinus, surrounded by the lymph in the spaces, take from it the elements needed for the production of their own peculiar secretion.

Dependent upon the nature of the activity of the epithelium of the glands, the general process of secretion may be said to comprise four distinct modes:—

1. Secretion by Filtration.—In this case the glandular epithelium does not manufacture any material; it utilizes the principles preëxisting in the blood and lymph. This kind of secretion is related to serous transudation, as of the pleuræ and peritoneum, but it is not a simple filtration. The selective action of the epithelium acts upon the transit of the secretion and varies the proportion of the constituents of the secretion according to the composition of the lymphatic and blood-plasma. To this style of secretion belong the water of the urine, the sweat, and the tears. The most important principles filtered are water, salts of the plasma, chlorides of potassium, sodium phosphates, lime, magnesia, and carbonic acid.

2. Secretion Proper — Production of New Principles. — Here glandular activity especially intervenes; the epithelial cell does not act as a simple filter. It modifies the nature of those products passing through it, or creates from them new products. In this class may be put the digestive secretion. The products thus formed by gland-cells vary for each gland; neither physiology nor histology is able to explain their manner of production. Thus, we are not able to explain in a satisfactory manner the chemical changes which make hydrochloric acid appear in the gastric juice, sulphocyanide of potassium in the saliva, bile acids in the bile, etc.

3. Secretion by Glandular Desquamation.—In the preceding types of secretion the gland-cell preserves its integrity; it does not do anything else except to allow the external materials to pass through it, changed or unchanged. However, in this type the cell itself falls and is eliminated to contribute to the formation of the product of secretion. This glandular desquamation is comparable to the epithelial desquamation which occurs during the life-history of the epidermis. Generally this desquamation is preceded by a chemical change of the gland-cells. This change is fatty, as in sebaceous secretion. The sebaceous fats and mucin form the special products of this group of secretions.

4. Morphological Secretion.—In this type the essential element of the secretion is a formed element. It is a specialized cell derived from a cell, together with a liquid which holds this anatomical element in suspension. Such is the spermatic fluid.

Secretion Defined.—The term *secretion* has been defined as the result of the special activity of the glandular tissues. It is the elaboration of fluid or semifluid mixtures by selection and formation from the fluids which surround the active cells, as well as from the substances of the cells themselves. Up to a certain point secretion is composed of two acts which are separated by a distinct line of demarcation.

1. Lymph passes through the wall of the capillary. This lymph spreads into the lymph-spaces which surround the acini, and it is from this lymph that the elements are taken out for the production of the secretory products. The filtration is under the

influence of the blood-pressure, and varies in its intensity as the arterial tension varies. It, properly speaking, is an accessory act of secretion.

2. The second feature is the *activity* of the *gland-cells,* which take from the lymph the materials necessary for secretion, to change them more or less. This phase is the essential act of secretion. It is dependent upon filtration to the extent that filtration furnishes the liquid which the glandular cells need and renews it when exhausted.

The activity of the gland-cells attains its maximum in general during the apparent repose of the gland. When the gland is not secreting, its cells are preparing substances peculiar to each secretion. This is true particularly of the ferments, as pepsinogen, trypsinogen, etc.

The two processes—filtration and gland-cell activity—may be separated from one another without producing any interference. Thus, secretion can continue when the head is amputated, and even if the circulation of the gland be arrested. Salivation can continue after both these events have occurred.

On the other hand, the injection of carbonate of soda into the salivary duct destroys the gland activity without affecting the circulation of the gland. Should the chorda tympani be stimulated filtration from the blood continues, but the gland does not secrete. There is an accumulation of lymph in the lymph-spaces until the gland becomes œdematous.

NATURE OF INTERNAL SECRETION.

This is not the same for all of the glands. The secreted product may be destined to destroy the noxious principles resulting from the functions of the organ, as of the liver and suprarenal capsules. Its aim may be to break up the excess of sugar, as is the case with the pancreas; or to prevent excess of a colloid material, as with the thyroid gland. The enrichment of the blood with useful principles is accomplished by the sugar of the liver. The testicle extract supplies more nervous energy.

THE THYROID.

The thyroid gland, when fully developed, has no excretory duct; so, with the spleen, suprarenal bodies, and thymus, it is usually classed under the head of ductless glands.

The thyroid is a soft, reddish body embracing the front and sides of the upper extremity of the trachea. It consists of a pair of lateral lobes united at their lower part by a transverse isthmus. The lateral lobes are oblong, oval, thicker below than above, and usually of unequal length. The weight of the thyroid is usually from one to two ounces, but is larger in the female. It is very liable to become hypertrophied, especially in the female; then it is called goiter.

The thyroid is a highly vascular organ, invested with a thin, fibrous membrane, and composed of a fibrous stroma, in the meshes of which a multitude of minute closed vesicles exist.

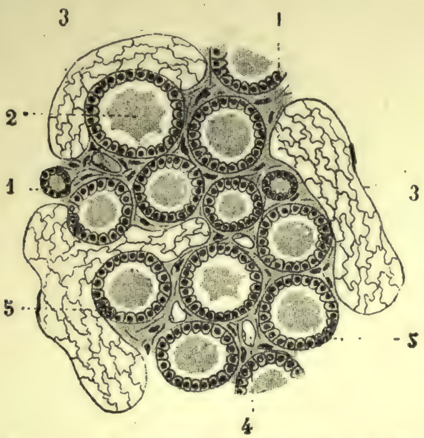


Fig. 144.—Structure of the Thyroid (Morat and Doyon). Lobule of the Thyroid after an Injection of the Lymphatic Vessels with Nitrate of Silver. Semi-schematic. (VIALLETON.)

1, 1, Vesicles. 2, Their colloid contents. 3, 3, Lymphatic vessels with epithelium stained with silver. 4, Blood capillary. 5, 5, Cells in the walls of the vesicles.

Each little lobule seems to be a completely closed sac—at least, no tubule is noticed emanating from it. The little sacs are filled with a transparent, amber-colored, viscid, nucleo-albuminous fluid. In the connective tissue surrounding each lobule there is a plexus of capillaries. With them there is found an abundant supply of lymphatics.

Vessels and Nerves.—The *arterial supply* for the thyroid body is gained from the superior and inferior thyroid arteries. These arteries are remarkable for their large size and numerous anastomoses. The veins form a *plexus* upon the front of the trachea and surface of the gland. From the plexus arise the superior, middle, and inferior veins. The *lymphatics* terminate in the thoracic and right lymphatic ducts. The *nerve-supply* to the thyroid body is derived from the middle and inferior cervical ganglia of the sympathetic and the pneumogastric. Their nonmedullated fibers adhere very closely to the vessels.

Function.—It was shown by one observer that gentle pressure upon the lobes of the gland caused the contents of the gland-acini, or vesicles, to flow into the peripheral lymphatics. This was later confirmed by the work of microscopists, and the colloid nature of the secretion was also recognized. The vesicular epithelium is a true secretory gland-tissue which separates the colloid material from the blood. The secretory character of the epithelium has been further shown by the injection of pilocarpine. Following its administration there results a remarkable increase in secretion of the colloid substance. It has been demonstrated that the expressed juice of a thyroid gland of a dog produced coma in another animal three hours after its administration.

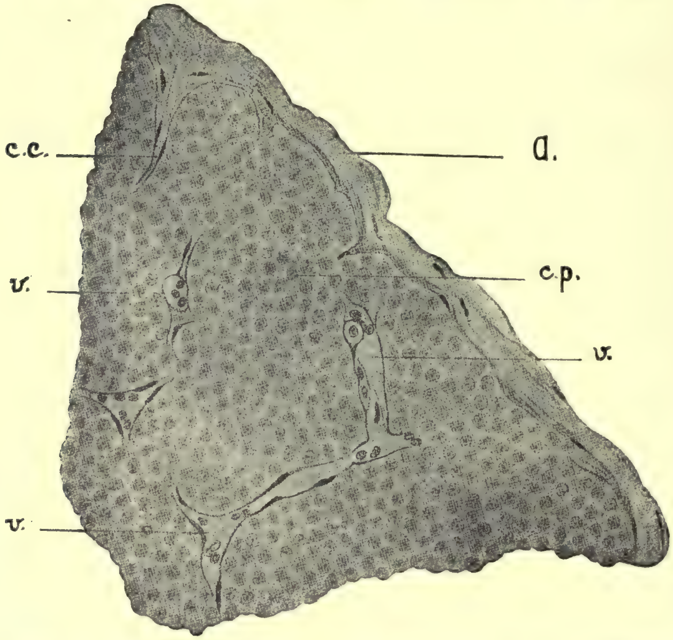


Fig. 145.—Parathyroid of Dog (Morat and Doyon). (VIALLETON.)

c, Capsule. *c.c*, Partition of connective tissue in the thickness of the organ. *c.p*, Epithelial cell of the parathyroid. *v*, Capillary.

Hence it must be concluded that the thyroid gland is a structure essentially connected with the metabolism of the blood and tissues. In performing its functions it is a blood-agent, both directly and indirectly. In the human fœtus the gland-tubes, or rather cylinders of epithelium, commence their secretory activity during the interval from the sixth to the eighth month. In proportion to the body-weight, the gland is heaviest at birth and diminishes notably toward the end of life. Therefore the thyroid gland is in functional activity before birth, and is of special metabolic importance in early extra-uterine life. Its value falls as the general vital processes decrease.

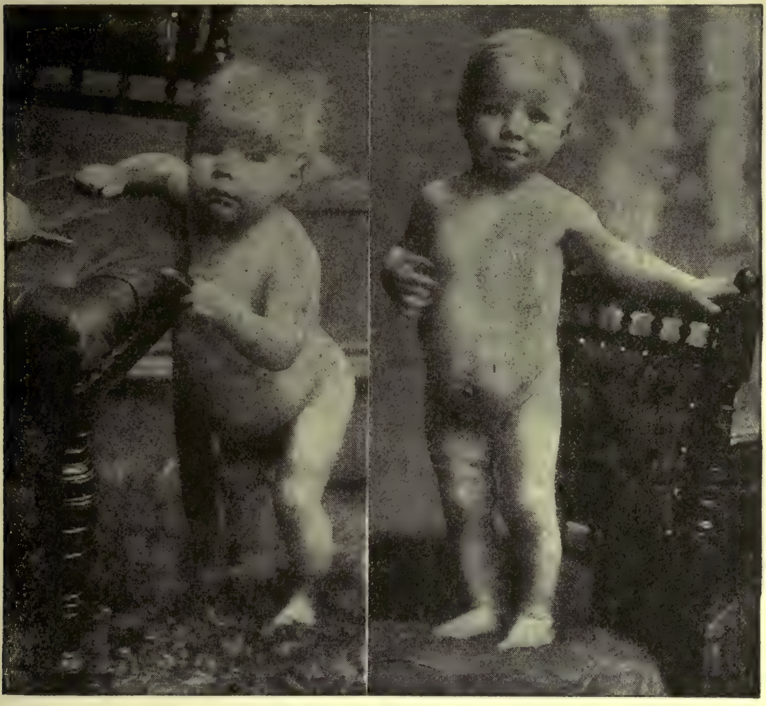


Fig. 146.—Illustrating Nicholson's Article on Thyroid Treatment in a Cretin (Arch. of Ped., June, 1900). (Raymond.)

***A*, Before treatment. *B*, After treatment.**

The thyroid body is one of those organs of great metabolic importance, since its removal or disease is followed by general disturbances. Experimental thyroidectomy is very much more fatal in young animals than in adults. The removal of the gland in aged carnivora is followed by the usual cachexia.

Cachexia Strumipriva has been found by all observers to occur with greater frequency when thyroidectomy has been performed on young individuals.

The classification of symptoms from removal of the thyroid is either (*a*) myxœdema, or (*b*) cretinism.

When the thyroid body is diseased or removed *from children* so that its functions are obliterated, there is produced a species of idiocy called *cretinism.*

A like condition *in adults* receives the name of *myxœdema.* Noticeable symptoms of this disease are slowness of both body and mind. There is also a peculiar condition of the skin wherein there is overgrowth of the subcutaneous tissue. In time this becomes replaced by fat. Myxœdema was believed to be an œdematous condition characterized by the presence of a large amount of mucin. That there is an excess of mucin has been determined, but it is not in proportion to produce this pathological condition. The disease is rather *a hyperplasia* of the connective tissue. The integument especially swells and the eyelids become puffy. At the same time the surface becomes dry and there is a tendency to shed hairs and superficial epithelium The hyperplastic change is followed by atropic changes, accompanied at first by slight fever; later the temperature becomes subnormal.

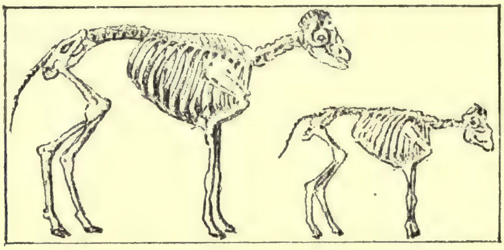


Fig. 146*a*.—Arrest of Development in a Sheep after a Thyroidectomy Done Six Days after Birth; the Larger One is the Skeleton of a Normal Sheep of the same Age. (Von Eiselsberg.)

In myxœdema the metabolism of nitrogenized substances is lowered; there is a diminution of urea and the total nitrogen of the urine. There is also a diminution of phosphoric acid, and the quantity of carbonic acid exhaled. This lowered metabolism lowers the temperature. In myxœdema there is a want of development in the cartilages of the epiphyses, an atrophy of the genital organs, ovaries and testicles, showing a relation between the thyroid function and the genital functions. In exophthalmic goiter, we have in a majority of cases an excessive secretion of colloid by the thyroid.

All of these various effects of thyroidectomy can be temporarily prevented by a graft of thyroid; they may also be caused to disappear either by injection of thyroid juice into a vein or under the skin. The same results may be attained by raw thyroid or thyroid juice by the mouth. If a graft can be made to "take," the effects are permanent. Removal of a permanent graft will be followed by all the symptoms of thyroidectomy.

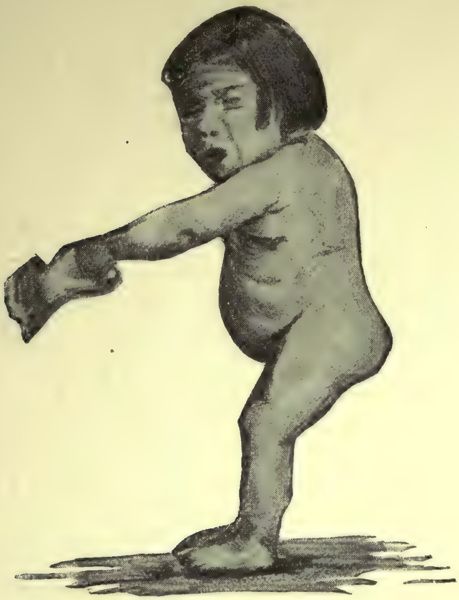


Fig. 146*b*.—A Case of Myxœdema in a Girl of About Ten Years of Age. (JEANDELIZE.)

The phenomena attending extirpation are due to the absence of a secretion which is formed within the thyroid, passing from it into the blood. This secretion is necessary for certain of the metabolic processes of the animal economy, especially for those connected with the nutrition of the central nervous system and connective tissues. Extracts of thyroid gland produce distinct pathological effects in the normal subject. An injection into a vein of the decoction of the gland lowers the blood-pressure and increases the caliber of the radial artery. From this it would seem that the juice has a distinct action upon the vascular system.

Whether the gland possesses the function of destroying toxic products of metabolism which would otherwise tend to accumulate in the blood is a point not yet understood.

Experiments have shown that at least a part of the thyroid gland must be allowed to remain after operations upon this gland. Otherwise, cachexia will follow.

The thyroid contains two albuminous bodies, the one containing iodine, the other having phosphorus. The first one has the character of a globulin and has received the name of thyreoglobulin and by reagents is changed into iodothyrin. The thyroid also contains choline, which depresses the heart and lowers blood-pressure.

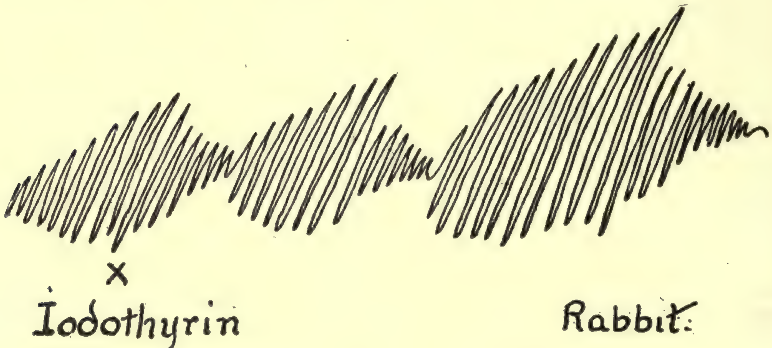


Fig. 147.—Effect of Iodothyrin on Intestinal Peristalsis.

It increases the extent of the peristaltic movements.

Hutchinson states that "if the presence of iodine in iodothyrin is essential to the activity of this substance, it is not so in virtue of its being iodine, but owing to the *form* of *organic combination* in which it occurs." It is estimated that the normal thyroid gland contains approximately *ten times* as much iodine as the hypertrophied glands of patients suffering from exophthalmic goiter. The thyroid seems to possess a peculiar affinity for iodine.

While our knowledge of the thyroid has been considerably extended by reason of modern research, there yet remains much that is very obscure.

Thyroid by the mouth reduces weight by an increase of the intake of oxygen and the output of carbon dioxide. This excessive burning of fat produces water, thus causing increased secretion of urine. It also increases the urinary nitrogen, probably due to proteid changes. It acts best in the pale, fat person.

Von Cyon has made a full study of the relation of the thyroid to the heart. He states that suppression of the activity of the thyroid or an injection of iodothyrin has an immense influence upon the entire nervous system of the heart and blood-vessels. He proves that the vagus participates in the innervation of the thyroid gland, or is at least closely connected with it. The function of the thyroid is to render harmless the salts of iodine, which have a toxic effect upon the vagi and sympathetic nerves by converting them into an organic compound, the iodothyrin. The latter compound has a stimulating effect upon these same nerves and at the same time

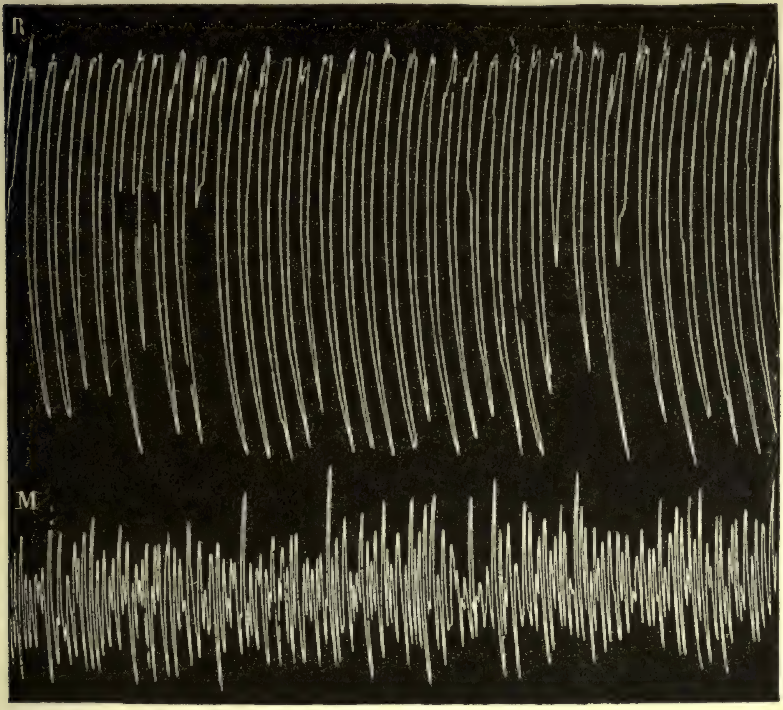


Fig. 147*a*.—Convulsive Movements after Thyro-parathyroidectomy in the Dog. (GLEY.)

Beginning of convulsive movements about sixty hours after the operation. *M*, Contractions of the shoulder muscles. *R*, Respiratory movements (Polypnœa), an hour after a strong convulsive attack. The rectal temperature a half hour after the attack was 41.35° C., and two hours after 43.1° C.

increases their power. The thyroid acts mechanically as a safeguard of the brain against engorgement. In a sudden increase of blood-pressure, whether from increased activity of the heart or from increased capillary resistance, the thyroid is capable of passing through its vessels a large amount of blood within a very short time, so as to take it back directly from the arterial into the venous system and thus prevent its entrance into the cerebral circulation.

PARATHYROIDS.

Sandstróem, a Swedish anatomist, first discovered the parathyroids. Vassale and Gley first established their function. In man the internal or superior parathyroids are located on the posterior surface of the thyroid gland, at the junction of the upper and middle third of the gland. The external or inferior are seated near the lower margin of the thyroid on its posterior surface. There are four parathyroids in man, two on each side of the median line. In the lower animals and in man there are accessory parathyroids, some located, according to Pepere, on the posterior surface of the thymus, in its capsule, or in its superficial interlobular grooves. In man they are often associated with epithelial, tubular or cystic formations. The structure of the parathyroids is different from that of the thyroids, both histologically and embryologically. The cells of the parathyroids have a large nucleus surrounded by a small amount of protoplasm in which

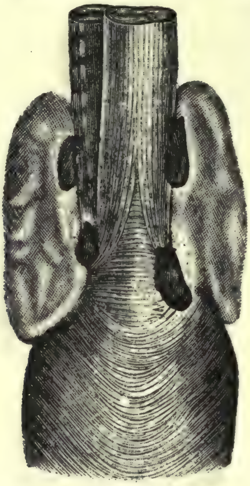


Fig. 147*b*.—The Four Parathyroids in Man, Posterior View. (Zuckerkandl.)

are granules more or less developed. They can be colored by reagents. They secrete a colloid substance which enters the blood through the lymphatics. When all the parathyroids are removed there is partial paralysis, especially of the extensors, trembling in all the muscles followed by a series of convulsive attacks with loss of appetite; there is often vomiting, dyspnœa, replaced during the convulsive attacks by polypnœa. The temperature rises during these convulsive attacks. This tetany begins in 24 to 48 hours after the operation in the dog and rabbit. The dog dies generally from the second to the fifth day, and, as a rule, in convulsions. The seat of the tetany is central. Robert Quest analyzed the brains of three infants dead of tetany and found the amount of calcium to be small, and the proportion between the amount of sodium and calcium to be changed. Oddo and Sarles found the urine in tetany in infants to have an exaggerated amount of phosphate of calcium.

Netter cured three cases of tetany in infants with chloride of calcium by the mouth.

W. G. McCallum and Voegtlin confirmed the results of Quest as to the lessened amount of calcium in the brain. They also found, as Oddo and Sarles did, an increased urinary excretion of calcium lately denied. McCallum and Voegtlin also found the calcium to be diminished in the blood and muscles to one-half the usual amount.

McCallum and Voegtlin found after parathyroidectomy, an increase in the urine of nitrogen, ammonia, and an increased ammonia ratio in the urine. They also found an increased amount of ammonia in the blood.

They also arrested tetany for 24 hours in dogs by seven grains of calcium by the vein. Halsted has cured tetany in man, due to operations on the thyroid and parathyroids by calcium. Injections of the parathyroid extract have been shown by Beebe to cause the symptoms of tetany to vanish for a time, but death finally ensued. Ott and Scott have found ten to twenty grains of pituitary extract, subcutaneously stops tetany in cats, and causes the shambling, trembling gait to be replaced by a normal one. McCallum has shown that transfusion of blood from a dog suffering from tetany did not cause the other dog to have it. Removal of the parathyroids produces tetany by a toxic agent in the blood, not by a deficiency of calcium. The parathyroid extract usually does not alter the pulse-rate to any extent. For the moment it usually slightly increases arterial tension and then decreases it. It greatly augments the urinary secretion by an action on the renal epithelium. It also augments uterine contraction and intestinal peristalsis. Pituitary extract when given, increases calcium in the blood. Adrenal extract causes the blood to retain calcium. Now, tetany can ensue in lactation, in rickets, in pregnancy, and from operations on the thyroid, involving the parathyroids. There is a juvenile tetany, and a tetany due to gastro-intestinal disorder. Eclampsia and paralysis agitans have been referred to changes in the parathyroid.

THE SPLEEN.

The spleen is deeply placed in the left hypochondrium. Its shape is a half-ovoid. Its consistency is comparatively soft, and its color is purplish. Its external convex surface is in contact with the diaphragm opposite the three or four lower ribs. Its internal surface is applied to the fundus of the stomach, to which it adheres by the gastro-splenic omentum. In the middle of the internal surface of the spleen there is a slight groove, the hilus, where the artery and nerves enter. The spleen usually is five inches in length, four inches in breadth, and from one to one and one-half inches thick. It has two coats: the outer serous and the inner fibro-elastic.

The spleen when torn has a deep reddish-black, pulpy appearance, resembling coagulated blood. This splenic pulp may be removed from the spleen by maceration, leaving a spongy mass composed of splenic blood-vessels associated with numerous trabeculæ of fibro-elastic tissue. Adhering to the side of the smallest arteries of the spleen are small, rounded, whitish bodies, the corpuscles of Malpighi, one-thirtieth to one-sixtieth of an inch in diameter. The splenic pulp contains red blood-corpuscles, granular corpuscles resembling lymphocytes in appearance, having an amœboid movement, and red corpuscles undergoing disintegration.

Function.—The extirpation of the spleen leaves life and health intact in animals and in man. All that results is a more or less pronounced hypertrophy in all the lymphatic ganglia of the body.

Direct irritation of the spleen, the direct or reflex irritation of the medulla oblongata, the application of ice-water to the left hypogastrium, and quinine cause a diminution of the spleen by contraction of the muscles of the capsule and trabecula. The spleen is congested during digestion, and when the portal circulation is interfered with, and in a great number of infectious diseases, notably typhoid and malarial fevers. The spleen is supposed by some to manufacture white blood-corpuscles, and this manufacturing reaches a pronounced activity when the organ is hypertrophied, as in leucocythæmia. The spleen, from its power to dilate, serves as a reservoir of blood for the portal system, especially for the blood-vessels of the stomach. Many of the purin bodies are found in the spleen, as xanthin, hypoxanthin, and uric acid.

Influence of the Nervous System Upon the Spleen.—The nerves that supply the spleen have their center in the medulla oblongata. Section of these nerves is followed by an increase in the size of the organ.

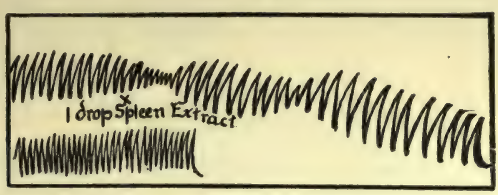


Fig. 148.—Effect of Extract of Spleen on Intestinal Peristalsis.

It has been shown by the oncometer that the spleen undergoes rhythmical contractions and dilatations by virtue of the regular contraction and relaxation of the muscular fibers found in its capsule and trabeculæ. Jones, of Baltimore, has shown that the spleen contains adenase, a ferment which converts adenin into hypoxanthin.

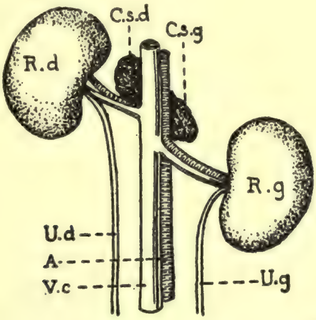


Fig. 149.—Adrenal Capsules of a Rabbit. (MORAT and DOYON.)

C.s.d, C.s.g, Capsules. *R.d, R.g*, Kidneys. *U.g*, Ureters. *A*, Aorta. *V.c*, Vena cava.

I have demonstrated experimentally that extract made from the spleen when injected into an animal will excite active peristaltic movements.

THE ADRENALS.

The adrenals are a pair of flattened triangular organs, one being situated upon the upper end of each kidney and inclined inwardly toward the vertebral column. Their posterior surface, moderately convex, rests against the crura of the diaphragm; their anterior surface, flatter than the posterior, on the right side is in contact with the liver, on the left side with the pancreas and spleen. The surfaces present vascular furrows, the largest of which at the base is distinguished as the hilus. These adrenals are brownish-yellow in color, of moderately firm consistence, and vary in size in different individuals and slightly on the two sides. Usually they are about one and one-half inches in breadth and height, and about one-fourth of an inch in thickness. On section we find an external layer, the cortex, and an internal layer of softer substance, the medulla.

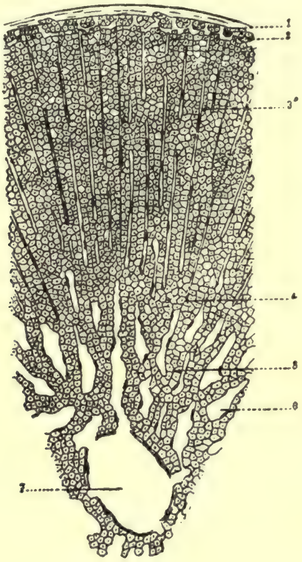


Fig. 150.—Section of Adrenal (Vialleton.)

1, Fibrous capsule. 2, Zona glomerulosa. 3, Zona fasciculata. 4, Zona reticularis. 5, Medulla. 6, Blood-vessel. 7, Central vein.

The cortical layer is yellow in color, of firm consistence, and presents a columnar appearance at right angles to the surfaces of the layer. Microscopically, it contains oblong receptacles occupying a fibrous stroma continuous with the fibrous coat of the body. In these receptacles are nucleated, transparent cells often containing oil-globules and a yellowish-brown pigment. Beneath the capsule is the zona glomerulosa, with cells in round groups; the next is zona fasciculata, with cells in columns; and the last is zona reticularis.

The *medullary substance* is composed of very irregularly shaped cells, rather closely, but irregularly, packed into a meshwork of fibrous tissue. In the interstices lie masses of multinucleated protoplasm, blood-vessels, and an abundance of nerve-fibers and cells. The cortex of the adrenals arises from the mesoderm; the medulla of the adrenals is a direct outgrowth of the sympathetic nervous system from the neural ectoderm.

The cells of the medulla are conspicuous in that they contain certain reducing agents. The agent which gives color-reactions has been termed *chromogen*. Just what this agent is chemically is not known, but it is believed to be the principle which raises blood-pressure when suprarenal extracts are injected subcutaneously. The active principle is, according to Abel, epinephrin; according to Takamine, adrenalin. Adrenalin has been prepared synthetically by Professor Hans Meyer, of Marburg, from methylaminoörthodioxyacetphenon. It constricts arterioles, contracts the iris, and produces glycosuria, like adrenalin. The cortex of the adrenals secretes choline.

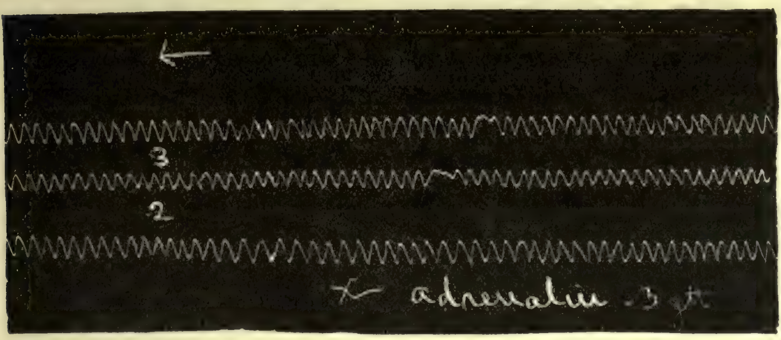


Fig. 151.—Effect of Adrenalin on the Volume of Inspired and Expired Air. Tracing with Gad's Aeroplethysmograph.

First line, normal. Second and third lines, showing the diminution of volume of air inspired.

Adrenalin is a white, crystalline substance with bitter taste, slightly soluble in water, and stable in dry state. It absorbs oxygen from the air, and is a strong reducing agent in alkaline and neutral solution. Its solution becomes red on standing. Chemically, it appears to be a secondary alcohol, and it is C_6H_3 (OH_2). CH (OH) CH_2. NH. CH_3. In the adrenals of patients dead of Addison's disease there was no adrenalin.

Blood-supply.—The blood-vessels of these suprarenal bodies are numerous. Each is supplied by the suprarenal artery from the aorta, together with branches from the contiguous phrenic and renal arteries. When the arteries enter the organ they ramify through the fibrous stroma and terminate in capillaries surrounding the receptacles of the granular cell-contents. The nerves are chiefly derived from the solar and renal plexuses of the sympathetic system, and are very numerous for the size of the organ.

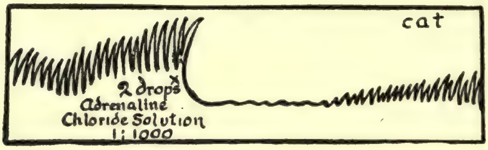


Fig. 152.—Effect of Adrenalin on Intestinal Peristalsis.

Function.—The function of the suprarenal bodies is still very obscure. The discovery that a relation existed between the bronzing of the skin of Addison's disease and a diseased condition of the suprarenals was a signal-point. It was learned that these small bodies are indispensable to life. The phenomena ensuing from their extirpation are due to a chemical alteration of the blood, and not to trauma. The ablation of one capsule is not necessarily mortal, but the destruction of both produces death very quickly. In the rabbit death follows

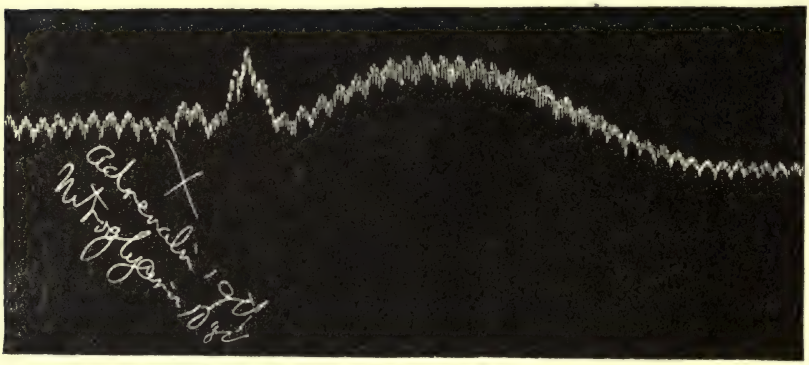


Fig. 153.—Cat. One drop of adrenalin solution and ten drops of 1-per-cent. solution of nitroglycerin, mixed and then injected per jugular.

The adrenalin counteracted the pressure-lowering by the nitroglycerin.

in nine hours; in the guinea-pig, in three hours. Death is preceded by a considerable weakness, true paralysis of the members and respiratory muscles, and epileptiform convulsions.

If the blood of animals dying from removal of the capsules be transfused into an animal that has just undergone the operation, there is produced a very rapid paralysis and death. Injecting an extract of the capsules into an animal from which the capsules have been removed slowed the symptoms and prolonged life. Hence, it has been concluded that the chief function of the suprarenal capsules is the neutralization of a poison analogous to curare. The means by which this is accomplished is a poison-destroying secretion in their cells. The poison to be neutralized is manufactured in the organism and accumulates in the blood in instances of lesion or removal of the suprarenals.

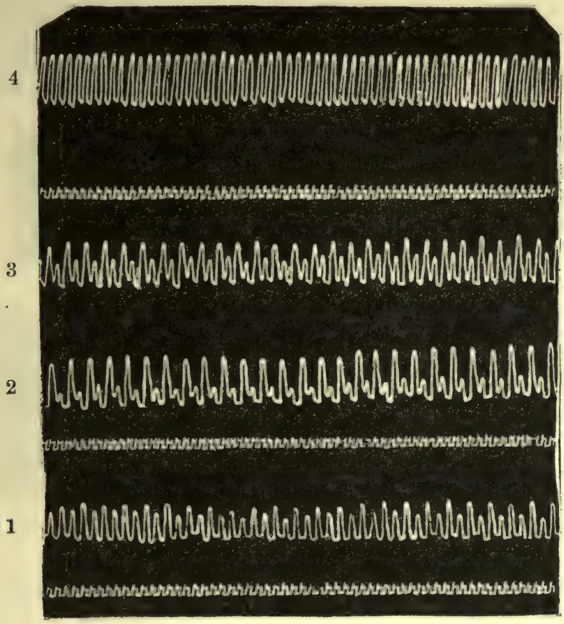


Fig. 154.—Turtle's Heart, Suspended by Lever.

1, Normal curve. 2, 3, 4, Curves after the gradual application to the heart of seven drops of adrenalin solution.

The effects of adrenalin upon any tissue are such as follow excitation of the sympathetic nerve, which supplies the tissue. It stimulates the myoneural substance or receptive substances of cells. It can be used as a test for the existence of sympathetic nerves in any organ. Its effects on one organ are shown by contraction; in another organ by inhibition. Thus, it causes contraction of the spleen and inhibition of the movements of the stomach, but in each case it resembles the effect of stimulation of the sympathetic nerve going to those organs. It is contraindicated in pulmonary hæmorrhage. In default of sympathetic innervation, plain muscle is indifferent to adrenalin. On irritation the splanchnics will not elevate the blood-pressure after the removal of the adrenals. Extirpation of the adrenals lowers the blood-pressure. Hence adrenalin excites the whole sympathetic system. Ott first showed that adrenal extract arrests peristalsis in diastole. This has been confirmed by several observers.

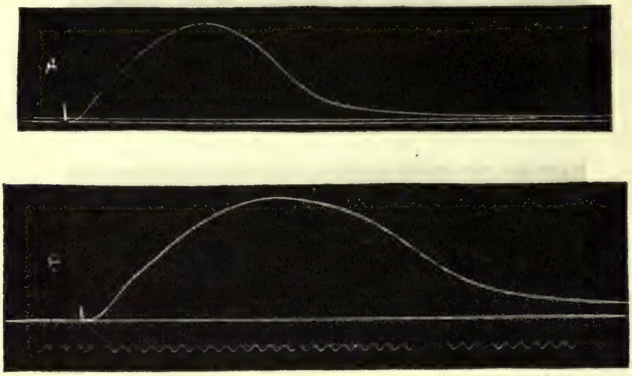


Fig. 155.—Effect of Suprarenal Extract upon Muscle-contraction in the Frog. (SCHÄFER.)

A, Normal muscle curve of gastrocnemius. *B*, Curve taken during suprarenal poisoning, but otherwise under the same conditions as *A*; time tracing; 100 per second.

Blum has shown that adrenalin causes glycosuria by an action on the glycogen of the liver.

Oliver and Schäfer found that when extracts of the suprarenals were injected into the circulation very noticeable phenomena resulted. Thus the arteries become greatly contracted, and the blood-pressure rises very rapidly. This vasoconstrictor action is independent of the main vasomotor center, which I have confirmed. Adrenalin dilates coronary arteries.

Adrenalin is a great muscle tonic, for it makes the cardiac contraction higher. It also slows the heart by a stimulation of the central end of the vagus. It stimulates the unstriped muscle of the arterioles through the myoneural substance, hence is a great vasoconstrictor, and thus arrests hæmorrhage. On striated muscle it prolongs contracture and thus causes the muscle to be slower in relaxing.

Nearly all the adrenalin is destroyed in the body, but I have shown that a minute quantity is excreted by the kidneys. One one-millionth of a gram of the dried gland will elevate the arterial tension.

The splanchnics are supposed to contain the secretory nerves of the adrenals.

In rabbits during pregnancy the suprarenal bodies enlarge, the outer cortex being twice the size of the medulla and inner cortex. Sexually precocious children have hypertrophied suprarenal capsules. Atrophy of suprarenal capsules is associated with want of pubic hair and of development of the genital organs. Hence the cortex of the adrenal is probably connected with the growth of the body and the development of puberty and sexual life. Repeated injection of adrenalin produces an experimental arteriosclerosis, with calcium deposits in the middle coat of the artery. Toxic doses produce agitation, dyspnœa, convulsions and death with pulmonary œdema and sometimes fibrillary twitchings of the ventricular muscles.

THE THYMUS.

The thymus body is a temporary organ which increases in size from the embryo up to two years after birth, and subsequently dwindles away. It occupies the upper part of the anterior mediastinal cavity behind the sternum and extends into the neck frequently to the thyroid gland. It rests upon the pericardium, aorta, and the trachea. It is a flat, triangular body, consisting of a pair of lateral and unequal lobes. It is of a pinkish-cream color, and varies in size and weight not only according to age, but also in different persons. At birth it is about two inches long and one and one-half inches wide at the lower part and two or three lines thick. It is composed of numerous angular lobules mixed with connective tissue. The lobules are subdivided into follicles, and each follicle has a cortex and medulla. In the medulla are spherelike bodies known as the concentric corpuscles of Hassall.

Chemical Composition.—The thymus is principally a lymph-gland. Nothing special is known of the concentric corpuscles. The presence of extractives, like xanthin, hypoxanthin, leucin, and adenin has been noted. The alkaline reaction of life becomes rapidly acid after death. The acid is sarcolactic acid.

The main constituent of the cells is proteid, especially nucleo-proteid. The total percentage in the thymus gland is about 12.29 per cent. When it is desired to produce experimental intravascular clotting, the thymus is usually employed as the source for the nucleoproteid. This property is not characteristic of the thymus, for it is found in all protoplasm.

Function.—Extirpation gives few positive results, but chemical investigation shows that the parenchyma of the gland contains a large number of products that indicate that it possesses very considerable metabolic activity. As long as the thymus gland exists, it seems to take part in the production of white corpuscles like other varieties of lymphatic tissue. Some authors claim for it the production of red corpuscles in early life.

Extracts of the thymus, when injected subcutaneously, have been shown by Ott to increase the pulse-rate, with a momentary rise of pressure, followed by a fall. This has been confirmed by Svehla and Swale Vincent. Svehla found that extirpation of the thymus of the frog kills it. Swale Vincent, however, did not find that removal of the gland of the frog was necessarily fatal, as his frogs lived thirty-six days after the operation. According to Vincent, extirpation of the gland of guinea-pigs did not affect the animal in any way.

PITUITARY BODY.

The pituitary body (hypophysis cerebri) is a small, reddish-gray, vascular mass, weighing from five to ten grains. It is oval in shape, situated in the pituitary fossa of the sphenoid bone, and is connected with the end of the infundibulum. The body is retained in position by a process of dura mater derived from the inner wall of the cavernous sinus.

The thyroid, adrenals and pituitary produce substances which are important and have an antagonistic action on blood-pressure. Hence they have been called regulators of nutrition and circulation.

Structure.—The pituitary body has two parts, a large anterior lobe of glandular structure, and a smaller posterior lobe. The anterior lobe, the hypophysis cerebri, arises from the epithelium of the mouth. The posterior lobe, nervous lobe, or infundibular body, is an outgrowth of the infundibulum of the brain, and in the adult is connected to it by a long stalk. Howell has shown that extracts of the anterior lobe of the hypophysis have no special action on the circulation. The posterior infundibular lobe has an internal secretion which increases the secretion of urine and dilates the blood-vessels of the kidneys.

In the pituitary there is a passage of colloid from the cells of the epithelial covering of the posterior lobe into nervous tissue and from it into the third ventricle to mix with the cerebrospinal fluid. Schnitzler and Ewald found iodothyrin in the pituitary colloid. P. T. Herring finds that removal of the thyroid is followed by an increased production of colloid by the pituitary. Masses of colloid lie among the cells and fibers of the nervous portion of the posterior lobe. The posterior lobe of the pituitary is an infundibular brain gland, emptying a colloid secretion into the third ventricle.

Shäfer has shown that the pituitary has a body unaltered by boiling which excites diuresis, the diuresis not being due to changes in blood-pressure. The infundibular part of the pituitary has a marked influence on the uterine contractions, according to Shäfer, Bell and Hick. The effect upon uterine contraction has also been confirmed by Ott and Scott. Paulesco has found that ablation of the nervous or infundibular lobe is compatible with an indefinite survival of an animal and is not followed by any apparent trouble. The removal of the pituitary is followed by coma, slow pulse and respiration, lowered temperature and death. He has shown that from a functional point of view the cortical layer of the epithelial anterior lobe is most important. These experiments have been confirmed by Redford and Cushing.

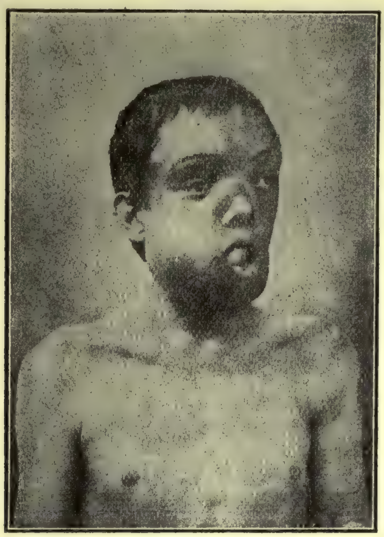


Fig. 155*a*.—A Case of Acromegaly. (Caselli.)

Ott and Scott have found 24 hours after the extirpation of the superior cervical ganglion that the local, venous or subcutaneous use of pituitary dilated the pupil, but not affecting the pupil on the sound side. In this respect it resembles the action of adrenalin on the mammalian pupil. The frog's pupil is dilated by adrenalin and pituitary.

Ablation of this body in the cat produces death in about two weeks. The symptoms resemble very much those that follow thyroidectomy. Extracts of the infundibular part elevate the arterial tension by a constriction of the arteries and slow the heart. This substance is not soluble in alcohol. From a saline decoction of the gland there was obtained an alcoholic precipitate which produced a fall of arterial tension; so that there seem to be two substances in this gland, antagonizing each other as regards arterial tension. Pituitary dilates renal arteries. Disease of this gland produces the condition known as acromegaly, in which the bones of the face and limbs become hypertrophied. It is also connected with giantism.

EXTERNAL SECRETIONS.

THE MAMMARY GLANDS.

The mammæ, or breasts, are accessory organs of the generative system. They secrete the milk. They exist in the male as well as in the female, but only in a rudimentary condition in the former. In the female they are two large, hemispherical eminences situated toward the lateral aspect of the pectoral region. They range between the third and seventh ribs. Before puberty they are of small size, but enlarge as the generative organs become more fully developed. They enlarge during pregnancy, especially after delivery. In old age they become atrophied.

The outer surface of the mammæ is convex, with just below the center a small, conical eminence: the nipple. The surface of the nipple is dark-colored, and surrounded by an areola of a colored tint. In the virgin the areola is of a delicate, rosy hue; about the second month after impregnation it enlarges and also acquires a darker shade of color. The color deepens as pregnancy advances; in some cases it becomes dark brown or even black. After cessation of lactation there is a diminution in the quantity of pigment, but the original hue is never regained. Change in the color of the areola is of importance in determining an opinion in cases of suspected first pregnancy.

The *nipple* is a conical eminence that is capable of erection from mechanical excitement. This is mainly produced by the contraction of its unstriped, muscular tissue, aided by its numerous blood-vessels. All tend to give it an erectile structure. The nipple is perforated by numerous orifices: the apertures of the lactiferous ducts. On its surface are very sensitive papillæ. Near the base of the nipple and upon the surface of the areola are numerous sebaceous glands. These become enlarged during lactation, their fatty secretion serving as a means of protection during the act of sucking.

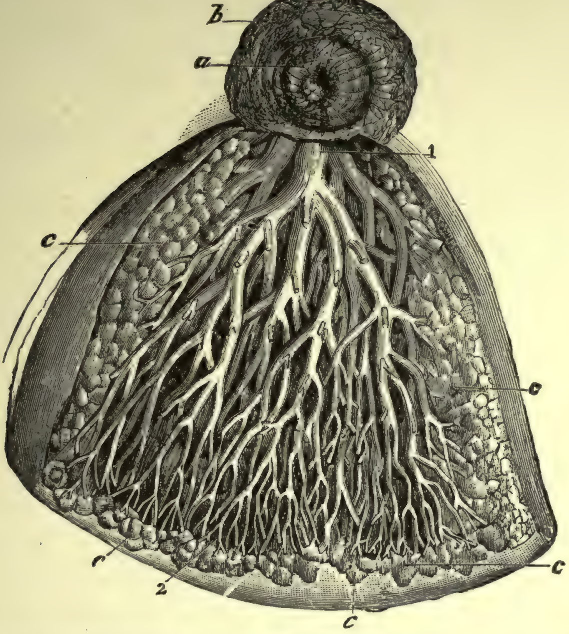


Fig. 156.—Mammary Gland of Human Female. (After LIEGEOIS.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

1, Sinus, or dilatation of one of lactiferous ducts. 2, Extremities of the ducts. 3, Lobules of gland. 4, Nipple, retracted in center. 5, Areola.

The nipple is made up of areolar tissue interspersed with numerous blood-vessels and plain muscular fibers. The fibers are arranged chiefly in a circular manner around the base, some fibers, however, radiating from the base to the apex.

Structure of the Mammæ.—The mammæ consist of gland-tissue. Like other glands, they are composed of large divisions, or *lobes,* which in turn are subdivided into *lobules.* The lobules and lobes are held together by means of fibrous tissue, while between the lobes are septa.

The mammary gland-tissue, in general, when free from fibrous tissue and fat, is of a pale-reddish color, firm in texture, and circular in form. The smallest lobules consist of a cluster of rounded vesicles, which open into the smallest branches of the lactiferous ducts. These small ducts unite to form larger ducts, which later terminate in a single canal. This latter corresponds with one of the chief subdivisions of the gland.

These main excretory ducts, about fifteen or twenty in number, are termed tubuli lactiferi. These present in their course a general convergence toward the areola, beneath which they form dilatations: *ampullæ.* These dilatations serve as small reservoirs for the milk. During active secretion by the gland the milk collecting in them distends them. Each lactiferous duct is of an average diameter of one seventy-fifth of an inch, expanding into the ampullæ, whose average caliber is one-fourth of an inch. At the base of the nipple the ampullæ become contracted again to pursue a straight course to its summit. Each duct pierces the nipple by a separate orifice, whose opening is about one-fiftieth of an inch. The ducts are composed of areolar tissue with elastic fibers and longitudinal muscular fibers. Their mucous lining is continuous at the point of the nipple with the integument. They are lined internally by short columnar, and, near the nipple, by flattened epithelium.

With the exception of the nipple, the general surface of the mamma is covered with fat. The latter is lobulated by sheaths and processes of connective tissue, which bind the skin and the gland together loosely. It is by this same manner that the gland is fastened to the great pectoral muscle beneath it.

Blood-vessels, nerves, and lymphatics are plentifully supplied to the mammary glands.

The *arteries* are derived from the thoracic branches of the axillary, the intercostals, and internal mammary. The *veins* describe, by their frequent anastomoses, a circle around the base of the nipple. This has been called by Haller the *circulus venosus.* From this branches run to the circumference of the gland. The caliber of the contained vessels, as well as the size of the glands, may be increased during pregnancy and lactation. The *lymphatics* principally run along the lower border of the pectoralis major muscle to the axillary glands. The *nerves* are derived from the supraclavicular and the intercostals. No secretory nerves of the mammæ exist.

Each *gland-acinus,* or vesicle, consists of a membrana propria, surrounded externally with a network of branched connective-tissue corpuscles. Internally there is a somewhat flattened polyhedral layer of nucleated *secretory* cells. The size of the lumen of the acini depends upon the secretory activity of the glands; when it is large the vesicle is filled with milk containing numerous refractive, fatty granules.

In the gland of a woman who is not pregnant or suckling the alevoli are very small and *solid.* They are filled with a mass of granular, polyhedral cells. During pregnancy the alveoli enlarge, while the cells undergo rapid multiplication. With the beginning of lactation the cells in the center of the alveolus undergo fatty degeneration and are eliminated in the first milk as *colostrum-corpuscles.* The lining cells of the alveolus remain to form a single layer of granular, short, columnar cells. Each possesses a spherical nucleus, and is attached to the limiting membrana propria. By means of metabolic processes within the protoplasm of the cells the fats, salts, milk-sugar, etc., are formed. During glandular activity, instead of one, two or more nuclei are seen; the well-formed one is near the base, the other nearer the free end of the cell. Near the border of the cell are seen numerous oil-globules and granules. Some of the larger oil-globules are seen projecting from the surface of the cell as if about to be extruded from it.

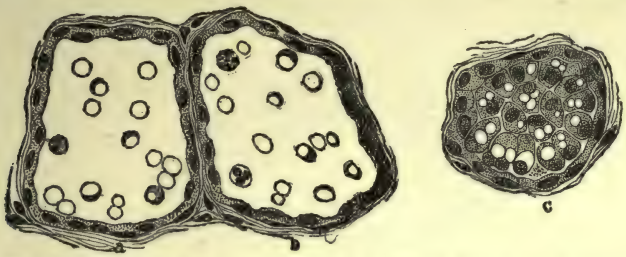


Fig. 157.—Dog's Mammary Gland in First Stage of Secretion. (Heidenhain.)

a, b, Section through the center of two alveoli of the mammary gland, the epithelial cells seen in profile. *c,* Surface view of the epithelial cells.

In addition to this, a division of the cell itself takes place: a parting of the cell-substance with a nucleus in it. The daughter-cell thus cast off passes into the alveolus to form a part of the milk.

The secretion of milk is an example of a secretion that is eminently the result of the metabolic activity of the secreting cell. The blood is the original fountain of the milk, but it becomes milk only by the action of the cells of the mammary gland: a metabolism of those cells.

Ottolenghi has found in the active mammary gland of guinea-pigs the presence of "Ninsen's globules," which are due to two causes: first, an increase of the nuclei of the epithelium of the gland; and second, an infiltration of the gland cells with leucocytes. This theory is opposed to that of Heidenhain, and makes the milk secretion chiefly a disintegration of the nuclei of the epithelium of the gland rather than a breaking up of the protoplasm.

Ottolenghi also saw in the milk glands, with islands of active gland tissue, other islands of a colostrum type—a type of relative rest.

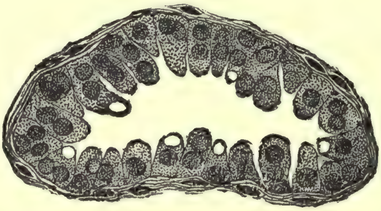


Fig. 158.—Mammary Gland of the Dog, Second Stage of Secretion. (Heidenhain.)

Colostrum.—At the beginning of the period of lactation milk is of a peculiar character and has received the name of colostrum. This term is also applied to the milk appearing during the first week after confinement. Colostrum is acid, possesses a yellow color, which becomes white toward the fourth day. It is viscid and has a mean density of 1.056. It contains, in addition to the fat-globules, colostrum-corpuscles. These are the degenerating polyhedral cells which filled the vesicles previous to lactation.

I have found that infusion of dried mammary gland decreases the pulse and increases arterial tension. The blood-pressure rises after removal of the main vasomotor center.

Functional Variations in Milk.—A substantial amount of nourishment augments the quantity of milk. Drinks have the same effect. An exclusive meat diet augments the proportion of fat in the milk; a small meat allowance in a mixed diet increases casein and diminishes the sugar. A vegetable diet diminishes the total quantity, lowers the amount of casein and butter, but augments the proportion of sugar of milk. A diet rich in fats does not augment the quantity of butter, but if kept up too long it diminishes it. Atropine and potassium iodide dry up the milk secretion; antipyrin is said to have a similar effect. Jaborandi increases it. Alcohol, frequently given in the shape of porter, increases the secretion of milk.

THE SWEAT-GLANDS.

The sweat-glands are the organs which furnish the means for the elimination of a large portion of the aqueous and gaseous materials excreted by the skin. They are found in almost every part of the integument, being particularly numerous where hairs are absent, as upon the palms and soles. Krause found the smallest number of them (400 for each square inch) upon the back and buttocks; the greatest number (2800 per square inch) on the surface of the palm of the hand and the sole of the foot. By this observer it was calculated that the total number of them is 2,400,000. These glands may become hypertrophic (in elephantiasis), thereby producing sudoriparous tumors upon the cheek. Atrophy also occurs.

In *structure* the sweat-glands are small, lobular, reddish bodies. Each consists of a single, convoluted tube, from which mass the efferent duct proceeds upward through the corium and cuticle. It is somewhat dilated at its extremity and opens upon the surface of the cuticle by an oblique valvelike aperture. The efferent portion of the duct in its course through the skin presents a corkscrew arrangement in those places where the epidermis is thick.

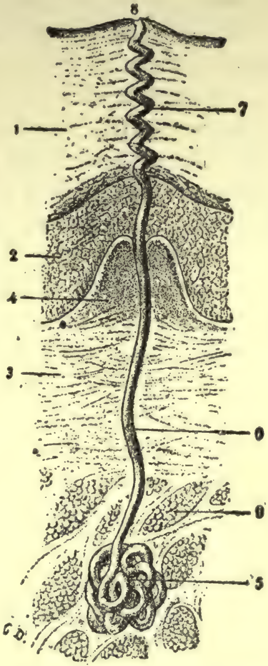


Fig. 159.—Sweat Gland. (HEDON.)

1, Epiderm. 2, Malpighian layer. 3, Derm. 4, Papilla. 5, Gland folded on itself. 6, Duct of gland. 8, Opening of duct. 9, Subcutaneous tissue.

The convoluted or coiled portion of the tube is the place where secretion takes place, and is usually known as the *secretory* part of the sweat-apparatus. Here the tube is lined by a *single* layer of clear, nucleated, cylindrical epithelium. Smooth muscular fibers in the larger glands are arranged longitudinally along the tube. Beyond the muscular coat is the basement-membrane; so that the duct has a definite outline and exists as an entity that is distinct from the surrounding tissues.

The distal portion of the tube serves the simple purpose of a conduit for the passage of the sweat-secretion to the skin surface. It contains no muscular fibers or basement-membrane. There is, however, a distinct lumen surrounded by several layers of cubical cells; so that by some authorities this portion of the apparatus is considered to be but an opening between epidermal cells.

Glands which are constantly active, as are the sweat-glands, must necessarily require a very liberal blood-supply. Each coil (the real seat of secretion) is surrounded by a network of capillaries, whose arrangement is such that the secretory cells are easily enabled to obtain the watery secretion from the blood-stream.

Nerves.—A plentiful supply of nerve-fibers in the form of a nerve-plexus ends in the glandular substance. That the secretion of sweat is not a mere filtration that varies according to the blood-pressure, but a process dependent upon a direct action of the nerve upon the gland-cell, has been demonstrated by Ott. In experiments upon cats certain changes were produced in the cell-protoplasm by changes in the activity of the nerve.

In the cat the sciatic was cut and the animal kept until the fifth day. At this time the pads of the feet were excised, placed in absolute alcohol, and when hard enough were cut into sections, stained with carmine solution, and mounted in glycerin.

In another cat the sciatic was exposed and the nerve feebly irritated for a period of two and one-half hours, when the pads of the feet were treated in the same manner.

Sections of the pads of the feet of each cat were then examined microscopically. It was found that the *irritated* cells were smaller than the resting cells, that their protoplasmic contents were more granular and more highly tinged with carmine solution, although left in it the same length of time as the resting cell. These facts have been confirmed by Renaut in the horse's glands.

Sweat is the secretory product of the sudoriferous glands. It is discharged in a continuous fashion upon the surface of the skin, there to be gotten rid of as vapor. As long as the secretion is small in amount it is evaporated from the surface *at once.* Because of this feature it is termed *insensible perspiration.* The skin is supple, fresh, and without any appreciable humidity.

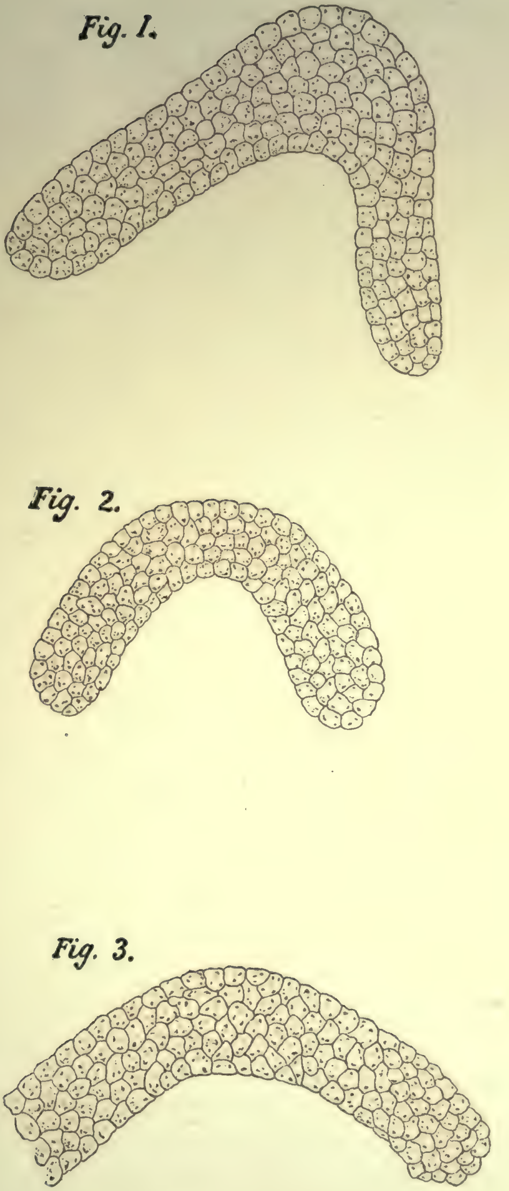


Fig. 160.—Section of Sweat-glands of Cat.

1, Section of gland five days after section of sciatic nerve. 2, Gland with sciatic irritated two and one-half hours. 3, Sweat-gland in normal condition.

When, however, the secretion of the glands is increased in quantity or its evaporation arrested, drops appear upon the skin. These drops of water form what is commonly known as sweat. During this condition the skin is also supple and soft, but is humid. There often is, in fact, a visible liquid.

Sweat is a more or less transparent *liquid*, of a salty flavor. It is constantly acid in reaction and has a specific gravity of 1.004.

The acidity is due to acid sodium phosphate. From its very ready contamination, it is impossible to obtain sweat in a pure state.

The relation of the sensible and insensible perspirations varies considerably with the temperature of the air. In round numbers, the total amount of sweat secreted by a man is *two pounds* in twenty-four hours.

The quantity of solid components of sweat is, on the average, 1.0 per cent. It may descend to 0.8 per cent. when there is an increase in the rapidity of the secretion. That means that in profuse perspiration it is the water which acquires the predominance. However, no matter what the celerity of the perspiration, there is a minimum of solid components: 0.8 per cent. This remains unchanged, showing that the sweat is a primitive secretion in character.

Sweat contains many and different members of the series of fat acids, neutral fats, alkaline sulphates and phosphates, lactic acid, and urea. Horse's sweat contains albumin.

The different strength and odor peculiar to the sweat of different animals is due to the variety and abundance of the volatile fatty acids. Of these, acetic, formic, and butyric prevail in general, with capronic and caprillic. To their prevalence in the armpits and feet is due the corresponding intensity of odor.

It has been calculated that about 0.08 per cent. of the sweat is *urea*. It may be increased greatly in cholera, by reason of its suppressed passage through the kidneys. There is often observed a crystalline deposit of this substance upon the surface of the body in death by cholera.

Carbonic acid and traces of nitrogen are found diffused in the sweat and so eliminated from the organism.

Perspiration is especially favored by the elevation of the body-temperature; by the wateriness of the blood; by the energetic action of the vessels of the heart; by increase of pressure in the cutaneous vessels, as during muscular exercise, etc.

Drugs.—Certain drugs *favor* sweating. Such are pilocarpine, Calabar bean, strychnine, picrotoxine, muscarine, nicotine, camphor, and the ammonias. Atropine, and morphine in large doses, *diminish* the secretion. I have found that muscarine and pilocarpine act on the peripheral end of the sudorific nerves.

Quinine, iodine, arsenic, and mercury, when introduced into the body, reappear in the sweat.

Although the nerves of the sweat-glands are not anatomically separated from others, yet their concurrence in the secretion is evident. In cutting the cervical sympathetic in a horse there is produced unilateral sweating (Dupuy). According to the increased intensity with which the cervical sympathetic is galvanically excited through the skin of man, there follows a lowered or increased perspiration of the corresponding side of the face. These facts, together with the known dilatation of the cutaneous vessels in profuse perspiration, show the influence of the vasomotor nerves.

Goltz and others have shown that by exciting the nerve of a limb the perspiration of it can be increased through the action of sudorific nerve-fibers. The same results have been attained even though the limb has been previously amputated and therefore no longer subject to circulation. It appears that the vasomotor and sudorific nerve-fibers run in the nerves by themselves.

Stimulating in man a motor nerve,—such as the tibial, median, or facial,—the part corresponding to the active muscles would perspire, even upon the side not excited. Vulpian and Ott have made experiments tending to prove the existence of inhibitory fibers of sweat.

The excretion of sweat takes place through *vis a tergo*, aided by the concurring contraction of the interlaced muscular fibers in the glandular glomerules. Besides, a kind of aspiration is exercised at the mouth of the gland by the evaporation of the liquid which arrives there. It is for this latter reason that air saturated with vapor slackens perspiration, especially when the other causes of transpiration do not act very strongly.

In the normal state the sweat and urine vary in quantity with the season; in the spring the sweat predominates over the urine, in winter the reverse is true. There is an inverse relation between the sweat and intestinal secretions. There is a very noticeable balancing between the sweats and diarrhœa of phthisis.

By varnishing the body death is caused. This *does not occur by retention of poisonous principles in the blood.* There are functional troubles, the most remarkable of which is the cooling of the body. This cooling is due to vasodilatation, and is the cause of death.

There seems to be a very steady relation between the amount of moisture exhaled from the lungs and the secretion of sweat. It is calculated in general that the perspiration is double that of the water from the lungs and, on an average, is one sixty-fourth of the weight of the body.

Suppression of Sweat by Cold.—All pathologists recognize cold as the cause of many lesions of an inflammatory nature. If this be true, it is produced not by suppression of sweat alone. It is probable that there is a transmission of impressions by the skin-nerves to the nerve-centers. These impressions generate, by an obscure pathogenic mechanism, probably bacterial, the inflammations of the viscera.

Role of Sweat-secretions.—The sweat is an important means for the elimination of water and alkalies.

It is also of very great use in the excretion of fatty volatile acids introduced into, or formed in, the organism. It is able to supplement the urinary secretion, for the skin is vicarious for the kidneys. It also carries off medicines and poisonous principles. It regulates animal heat, since the evaporation of the water of sweat cools the body. The secretion of sweat is independent of the circulation; however, there exists a relationship between them. Thus, an abundance of sweat requires a full, free circulation. As the salivary glands need a flow of blood to furnish materials for secretion, so do the sweat-glands.

I have shown elsewhere that the sudorific centers are in the *spinal cord* and that their fibers run in the *lateral columns.* The sweat-centers are excited by an excess of CO_2 in the blood and by overheated blood. Camphor, acetate of ammonium, and pilocarpine excite sweat by a direct action on the centers. Muscarine excites sweat by a local action; atropine arrests it.

Pathological.—Besides the components mentioned, biliary pigment is also found in the sweat of persons having jaundice; sweat becomes bitter after strong doses of quinine from its appearing in this medium during its elimination from the body. The sweat of diabetes is found to be sweetish, although the presence of glucose in it has not been definitely determined. The red pigmentation sometimes found is attributed to the blood-globules, crystals of which were found in the sweat. Hebra saw it succeed menstruation; but it may also occur in serious nervous disease and in yellow fever. In the offensive sweat of feet there are found leucin, tyrosin, valerianic acid, and ammonia.

THE SECRETION OF THE URINE.

In a perfectly normal being the problems of waste and repair are balanced to a nicety. This equilibrium owes its maintenance to the proper action of the various glands of the economy, whether secretory or excretory. As we know, the tissues of the body are bathed in lymph containing in solution the compounds that are necessary for their nourishment: proteids, carbohydrates, fats, salts, and gases. By reason of the organism exercising its various functions, waste follows in direct proportion to the activity of the tissues. The worn-out and effete materials first find their way into the lymph and from it into the blood-stream, to be later eliminated from the economy, else deleterious results will follow their retention in the body. It is by the selective action of the cells of the various glands of the body that these useless substances are removed from the blood: that is, *secreted* by them and converted into such form as to be readily removed to the exterior of the organism by *excretory* processes. In the main, the products to be removed are urea and allied nitrogenous bodies, carbon dioxide, salts, and water. Most of the water, salts, urea, and allied substances are eliminated as components of the urine by those most important organs, the kidneys. These organs are of vital importance, since nearly all of those waste-products containing nitrogen are eliminated in the urine.

The kidneys secrete the urine. Their excretory functions, a matter of everyday observation, represent the extent of their external secretion; although not yet definitely settled, the consensus of opinion leans toward the kidneys possessing an *internal* secretion as well.

Morphology of the Urinary Apparatus.—The secretory organs of the urine are the *kidneys*. They, two in number, are compound tubular glands, situated in the back part of the abdomen. The kidneys are extraperitoneal organs, lying behind the peritoneum and resting upon the lumbar portion of the diaphragm and the anterior layer of the lumbar fascia. The upper borders of the kidneys touch a plane that is on a level with the upper border of the twelfth dorsal vertebra; their lower extremities are on a level with the third lumbar vertebra. The right kidney is usually somewhat lower than the left, probably because of the pressure exerted by the liver, against whose lower surface the kidney rests. In front it is in relation with the liver, the descending portion of the duodenum, and the hepatic flexure of the colon; the left kidney lies in relation with the fundus of the stomach, the tail of the pancreas, and the descending colon. Superiorly lie the suprarenal bodies. The kidneys are incased in a variable quantity of fat and loose areolar tissue, to which has been given the name *perirenal fat.*

The kidneys are firm organs, of variable color, between light red and bluish, according to the degree of congestion; each kidney weighs about four and one-half ounces. In shape they resemble a bean, their length being double their width; each kidney is about four inches in length, two inches in width, and one inch in thickness.

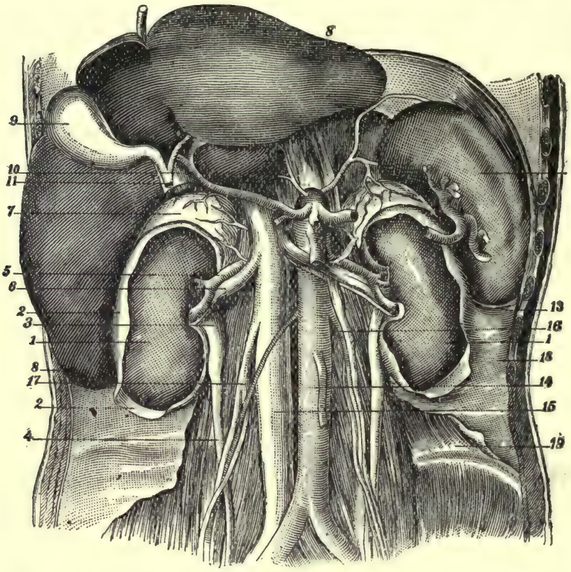


Fig. 161.—Relations of the Kidney. (After Sappey.)

1, 1, The two kidneys. 2, 2, Fibrous capsules. 3, Pelvis of the kidney. 4, Ureter. 5, Renal artery. 6, Renal vein. 7, Suprarenal body. 8, 8, Liver raised to show relation of its lower surface to right kidney. 9, Gall-bladder. 10, Terminus of portal vein. 11, Origin of common bile-duct. 12, Spleen turned outward to show relations with left kidney. 13, Semicircular pouch on which the lower end of the spleen rests. 14, Abdominal aorta. 15, Vena cava inferior. 16, Left spermatic vein and artery. 17, Right spermatic vein opening into vena cava inferior. 18, Subperitoneal fibrous layer or fascia propria dividing to form renal sheath. 19, Lower end of quadratus lumborum muscle.

The internal border of each kidney is concave, the concavity being directed slightly forward and downward. This portion of the kidney is divided by a deep, longitudinal fissure, bounded by a prominent anterior and posterior lip. The fissure is known as the hilus, and allows of the passage of the vessels, nerves, and ureter to and from the substance of the kidney. Just within the hilus is a dilated fossa known as the *sinus*, which contains the renal artery, the vein, and the pelvis of the kidney. The relation of the structures passing in and out of the hilus from before backward are: vein in front, artery in the middle, and the duct, or ureter, behind and toward the lower part. By keeping in mind these relations one will be able to distinguish the right from the left kidney after their removal from the body.

In the funnel-shaped cavity of the renal pelvis is the *ureter*. From the kidney it passes over the psoas muscle, converging toward that of the opposite side to cross the external iliac artery and vein. It opens obliquely into the base of the urinary bladder. In females the ureter embraces the neck of the uterus. The ureters have an average length of eighteen inches and a lumen which averages that of a goose-quill. Just before piercing the bladder-wall the lumen of the ureter becomes appreciably smaller.

The *urinary bladder*, situated between the symphysis pubis and the rectum in man, between the symphysis and the uterus in woman, is held in position by the urachus and lateral ligaments. Its base rests upon the perineum and anterior wall of the rectum in man, upon the anterior wall of the vagina in woman. From the base of the bladder the urethra takes its origin.

The opening for the latter bears such a relation to the entrance into the bladder of the two ureters that there is formed the *vesical triangle*. The openings for the ureters are about sixty millimeters apart.

The capacity of the bladder varies with its extensibility, so that it is possible for the viscus to be so distended that its upper border may reach the umbilicus or even the epigastric region. Ordinarily the capacity in both sexes is about a pint.

The bladder receives its *blood-supply* from the branches of the anterior trunk of the internal iliac. The *lymphatic* vessels communicate with the lumbar ganglia. The *nerves* are derived from the sympathetic, sacral, and probably some fibers from the pneumogastric also.

General Structure of the Kidney.—Beneath the perirenal fat lies the proper tunic, or covering, of the kidney, commonly called the *capsule*. In health it is a smooth, thin, but tough, fibrous covering, closely adherent to the organ, but from which it can be readily stripped. By reason of this separation, however, fine connective-tissue processes and minute blood-vessels are torn which have served as a means of attachment for the capsule. The denuded kidney presents a smooth, even surface of a deep-red color.

For a proper naked-eye study of the kidney the organ must be divided longitudinally from the hilus to its outer border, and the fat and areolar tissue must be removed from the vessels and ureter. It will at once be seen that the kidney is composed of a *cavity,* somewhat centrally located, and the *parenchyma* of the organ, nearly surrounding the central cavity. This compartment, as before stated, is termed the *sinus,* and is lined by a continuation of the fibrous covering of the kidney. It is through the *hilus* that this fibrous covering passes, as do the renal vessels and ureter.

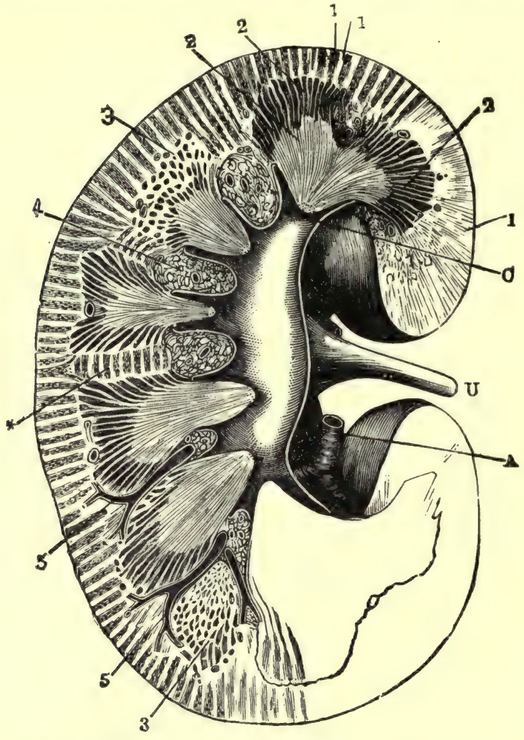


Fig. 162.—Section of Kidney. (LANDOIS.)

1, Cortex. 1′, Medullary rays. 1″, Labyrinth. 3, Medulla. 2′, Papillary portion of medulla. 2″, Boundary layer of medulla. 4, Fat of renal sinus. 5, Artery. *A*, Branch of renal artery. *U*, Ureter. *C*, Renal calyx.

The ureter, upon entering the sinus, is expanded into a funnel-shaped sac, the *pelvis.* The pelvis soon divides into several branches

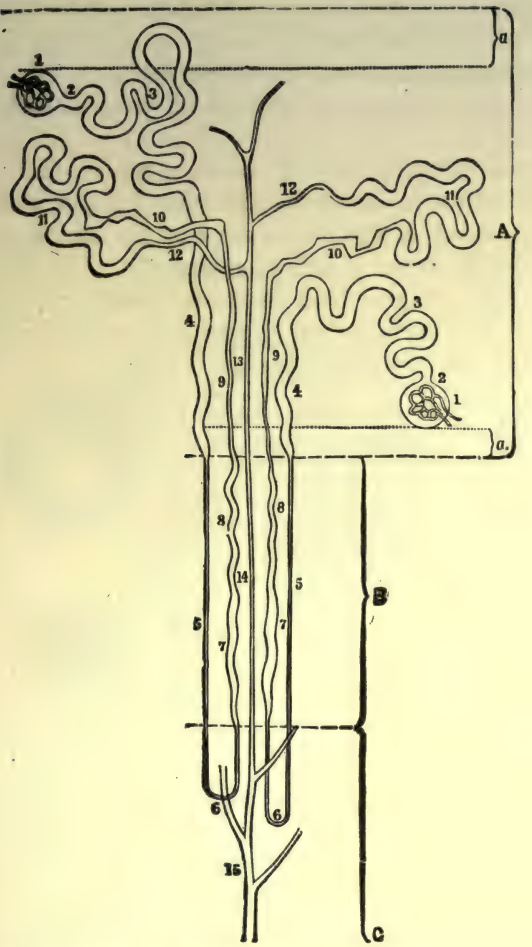


Fig. 163.—Diagram of the Course of Two Uriniferous Tubules.
(Landois.)

1, Malpighian tuft surrounded by Bowman's capsule. 2, Constriction on neck. 3, Proximal convoluted tubule. 4, Spiral tubule. 5, Descending limb of Henle's loop-tube. 6, Henle's loop. 9, Wavy part of ascending limb. 10, Irregular tubule. 11, Distal convoluted tubule. 12, First part of collecting tube. 13, Straight part of collecting tube. *A*, Cortex. *B*, Boundary zone. *C*, Papillary zone.

of smaller size, and these immediately subdivide into from eight to twelve infundibula, or *calyces,* from their resemblance to cups. Into each calyx there projects the point or extremity of a renal pyramid. The blood-vessels lie within the sinus, between its wall and the exterior of the pelvis, before subdividing and entering the parenchyma of the organ.

The *parenchyma* is seen to be composed of two portions, an external, investing *cortical* portion, and an inner *medullary,* or pyramidal, portion.

The *cortex* is light brown in color, granular, and very friable. The granular aspect is due to the presence of Malpighian corpuscles, which are separated at regular distances by medullary rays, or striæ, which give to the cortex a radiate appearance. The boundary zone is darker, and also striated from blood-vessels and uriniferous tubules. It is through this portion that arteries and nerves enter and veins and lymphatics pass from the kidney.

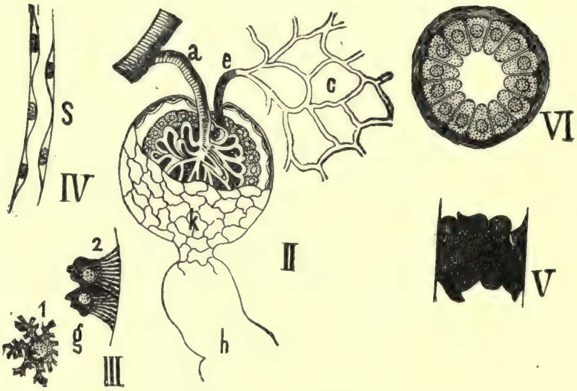


Fig. 164. (Landois.)

II. Bowman's capsule and glomerulus. *a*, Vas afferens. *c*, Vas efferens. *k*, Endothelium of the capsule. *c*, Capillary network of the cortex. *h*, Origin of a convoluted tubule.

III. "Rodded cells" from a convoluted tubule. 2, Seen from the side, with *g*, inner granular zone. 1, Seen from the surface.

IV. Cells lining Henle's looped tubule.

V. Cells of a collecting tube.

VI. Section of an excretory tube.

The *medulla* is composed of from eight to twelve pyramids, or cones, of pale-red, striated tissue, known as the *pyramids* of *Malpighi;* their number depends upon the number of lobes composing the organ during the fœtal state. It is the apices of these cones which dip down into the calyces of the pelvis.

Minute Anatomy.—The kidneys consist of numerous tubular glands intimately united together. The tubes, known as *tubuli uriniferi,* take their origin in the labyrinth of the cortex as distinct globular dilatations, each of which is known as Bowman's capsule.

The capsule surrounds a small, red, spherical body known as the *glomerulus,* or Malpighian corpuscle, after Malpighi, its discoverer. The capsule, about one one-hundredth of an inch in diameter, is constricted at its *neck* to form a tube. Beyond this constriction the tube pursues a very convoluted course through a considerable extent of the cortical area, as the *tubulus contortus,* which is about one six-hundredth of an inch in diameter. Soon the convolutions disappear to give place to a more or less *spiral* tube as it approaches the medulla: *spiral tube* of *Schachowa.*

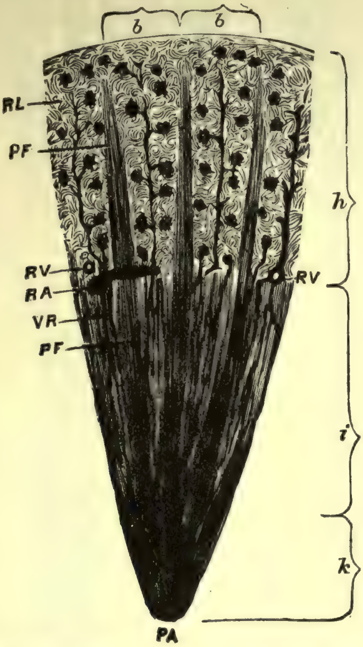


Fig. 165.—Longitudinal Section of a Malpighian Pyramid. (Landois.)

h, Cortex. *i,* Boundary or marginal zone. *k,* Papillary zone. *PF,* Pyramids of Ferrein. *RA,* Branch of renal artery. *RV,* Lumen of renal vein receiving an interlobular vein. *VR,* Vasa recta. *PA,* Apex of renal papilla. *b, b,* Embrace the bases of the renal lobules.

At the boundary-line between cortex and medulla the tube becomes suddenly smaller and is now perfectly straight, forming the *descending limb* of *Henle's loop,* dipping down for a considerable distance into the pyramid. By the sudden changing of its course backward, but still parallel with its original course, there is formed the *loop* of *Henle,* which, continued upward to the cortex, constitutes the *ascending limb of Henle's loop.* Ascending into the cortex it

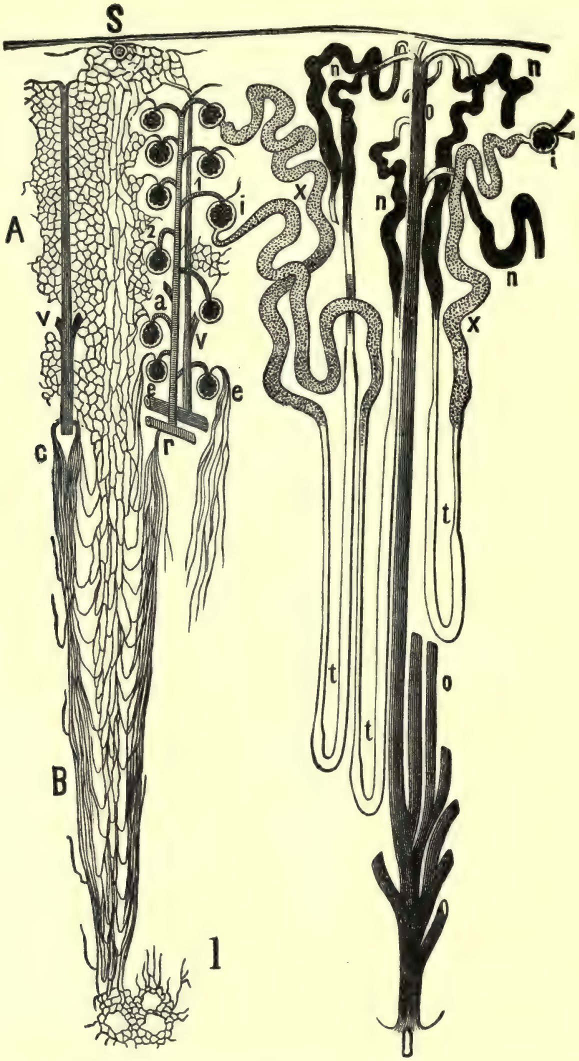


Fig. 166.—Blood-vessels and Uriniferous Tubules of the Kidney (Semidiagrammatic). (Landois.)

A, Capillaries of the cortex. *B*, Of medulla. *a*, Interlobular artery. 1, Vas afferens. 2, Vas efferens. *r*, *e*, Vasa recta. *c*, Venæ rectæ. *v*, *v*, Interlobular vein. *i*, *i*, Bowman's capsule and glomerulus. *x*, *x*, Convoluted tubules. *t*, *t*, Henle's loop. *o*, *o*, Collecting tubes. *O*, Excretory tube.

becomes dilated, irregular, and angular,—zigzag,—which ends in the distal convoluted tube, finally to terminate in a short *curved tube*, which empties into the straight, or *collecting*, *tube*.

The collecting tubes, as they run toward the medulla of the kidney, unite with other distal convoluted tubules. They also unite at acute angles with adjacent collecting tubes finally to pass to the papillæ. The loops of Henle and the collecting tubes constitute the *tubuli recti.* Each uriniferous tubule is thus completely isolated as far as the junction of the distal contorted tubes with the collecting tube.

A portion of the loops of Henle and the upper part of the collecting tubes form the little cones in the cortex, visible to the eye and known as the *pyramids* of *Ferrein.*

The *Malpighian corpuscle* consists of a spherical plexus or knot of blood-vessels, the *glomerulus,* which is inclosed in the dilated end of the urinary tubule, known as the capsule of Bowman. As the capsule has been infolded by the glomerulus being pushed into it (as one would infold the end of the finger of a glove by the tip of one's finger), it follows that the capsule consists of two layers. The internal one, covering the glomerulus closely, is formed of cubical cells, while the external one, formed of flat, polygonal cells, passes on into the neck and thence forms the wall of the convoluted tubule. The cells in this portion of the tube are shaped like a cone, the narrow end being directed toward the lumen of the vessel; owing to the fine, longitudinal lines upon each cell, it has a rodlike appearance: *rodded cell.*

The Blood-vessels.—The renal artery divides at the hilus into four or five branches. The four or five main branches continue to divide and subdivide and so pass into the parenchyma of the organ. They course *between* the papillæ to run up to the boundary between the medulla and cortex. Here the vessels bend at right angles to form a series of loops or arches, their convexity toward the cortex of the kidney. From the convex sides of the arches there spring vessels at regular intervals termed *interlobular,* or *radiate, arteries.* They sometimes run up so as to divide the cortex into small lobules, coursing singly between each two medullary rays. These radiate arteries give off numerous small branches which run at right angles, each one entering a Malpighian corpuscle. It is usual for the point of entrance of the artery to be diametrically opposite the point of origin of the urinary tubule. These last-named vessels, the *vasa afferentia,* break up into very fine vessels within the capsule to constitute the glomerulus. They are supported by connective tissue, and form a veritable tuft of capillary vessels. It is of interest to note that each glomerulus is covered by a single layer of flat, nucleated, epithelial cells, these even dipping down between the capillaries.

From the center of the glomerulus there proceeds a vessel that is somewhat smaller than the afferent vessel, known as the *efferent vessel;* it is a vein, and leaves the capsule very close to the point of entrance of the vas afferens.

The efferent vessel also divides to form a secondary capillary network, the renal portal system, with elongated meshes in the situation of the pyramids of Ferrein; from this plexus arise the interlobular veins which run parallel to the interlobular arteries.

The *medulla* of the kidney receives its arterial supply from the *arteriæ rectæ;* these latter are vessels which spring either from the arterial arches or from the interlobular arteries. According to some authors, they may be derived from the afferent vessels of the deepest and largest glomeruli. Within the pyramids the arteriæ rectæ divide and subdivide to form a plexus of capillaries which eventually merge into the *venæ rectæ,* to empty into the venous trunks at the boundary between the medulla and cortex.

The *renal veins* arise from three sources: (1) the venous plexus beneath the capsule, (2) the plexus around the tubuli contorti, and (3) the plexus located near the apices of the pyramids. Within the sinus the larger branches from these plexuses inosculate to form the renal veins, which pass through the hilus to empty into the inferior vena cava.

The vasa recta circulation is of prime importance in that it forms a sidestream through which much blood may pass without being compelled to traverse the glomerulus. It is very apparent that this circulation is highly useful in conditions of kidney congestion as a sidestream.

Three kinds of capillaries are found within the kidney: (1) *glomerular,* (2) *efferent capillaries,* and (3) capillaries of the *vasæ rectæ.* The kidney, for its size, is abundantly supplied with blood.

Lymphatics.—The kidneys are richly supplied with lymphatics, occurring as slits. The renal lymphatics terminate in the lumbar lymphatic glands.

Nerves.—The nerves of the kidney accompany its blood-vessels, ganglionic plexuses being numerous. They are from the renal plexus, coming originally from the solar plexus.

Physical Properties and Chemical Composition of the Urine.

The analytical study of the urine is of great value to the physician and surgeon because of the knowledge which it gives concerning the processes of metabolism occurring within the body. The nature and amount of the various end-products of metabolism are carefully investigated as they occur in the urine, whether they be normal or pathological. From these investigations corresponding conclusions are drawn.

Neutral substances are, normally, either absent or present in but minutest quantities. All of the important and more abundant constituents of normal urine are either basic or acid in reaction. These bases and acids must, therefore, enter into various combinations, making the urine a *solution* of *salts.* The quantity of separate ingredients found analytically might lead the observer to consider the metabolic processes as pathological, yet in solution perfectly normal compounds are formed by these same components. The error is due to the inability to study the properties of the urine as a complex unit: the effects certain components have on others, their avidity for one another, and the consequent equilibrium established.

The Urine.—The normal human urine, recently passed, is a clear liquid of a straw color. It has an average specific gravity of 1.020, is of aromatic odor, and a salty bitter flavor. In reaction it is acid; only in pathological conditions does it become neutral or alkaline.

Receding from the temperature of about 100° F., which is proper to it in the act of passing, it loses its aromatic odor and acquires a peculiar odor, described as urinous. In healthy persons it has been seen to be phosphorescent during micturition, probably from the liberation of phosphorus by its salts. In cooling, urine becomes turbid, with a small cloud suspended in the thickness of the liquid, formed from the epithelium of the uriniferous tubules. It leaves, besides, especially if very much colored, sediments of different appearance, according to the varying composition.

The *quantity* of urine secreted by the kidneys of a healthy adult man in twenty-four hours ranges from 1200 to 1700 cubic centimeters, or about 50 ounces; in females the quantity is less. During sleep the amount secreted is less than at other times, so that the minimum secretion is placed between 2 and 4 A. M. and the maximum from 2 to 4 P. M.

While the average daily secretion is placed at 50 ounces, yet it must be borne in mind that this quantity is not fixed, but may be very variable, dependent upon numerous conditions.

The amount of urine is *diminished* by reason of profuse sweating, extensive diarrhœa, thirst, diminution in blood-pressure, after severe hæmorrhage, and in some forms of kidney disease.

Increase in urinary secretion (polyuria) is produced by an increase in blood-pressure, by imbibing excessive draughts of liquids, by any condition whereby the cutaneous blood-supply is diminished (cold will do this). Polyuria is likewise produced by the administration of drugs which raise arterial tension, as digitalis and alcohol, and by caffeine and sparteine, which stimulate the renal cells.

The influence of the nervous system upon the secretion of urine is very beautifully demonstrated by cases of hysteria. Hysterical patients void excessive amounts of a very pale, watery urine.

The specific gravity, as previously stated, averages 1.020; that is, the mean between 1.015 and 1.025. The specific gravity varies inversely to the quantity excreted. When for any reason, not pathological, there is polyuria, the mark drops proportionately, registering as low as 1.002. As a result of profuse sweating and abstinence from liquids, the mark may reach 1.035 in healthy individuals.

Acidity.—The acidity of the urine is chiefly due to acid phosphate of sodium. There are two tides in the acidity of the urine. During digestion the formation of the hydrochloric acid in the stomach frees certain bases in the blood, which, when excreted, diminish the acid reaction of the urine. This is called the alkaline tide. The acid tide is after a fast, and hence occurs early in the morning.

Ordinarily it should be remembered, when taking the specific gravity of urine, that anything below 1.010 should at once excite suspicion of polyuria, with probably albumin; when above 1.030, diabetes mellitus or some febrile condition may be present.

The *urinometer* is the instrument used to ascertain the density of any given sample of urine, and is so graduated that, when floating in distilled water, it registers 0 degrees, by which is meant 1000. The urine is placed in a tall, cylindrical glass of proper width so that the urinometer will not adhere to its sides. After cessation of the oscillations of the instrument, the observer carefully sights along the surface of the urine to note the number registered. This precaution is taken because the capillarity along the stem of the instrument causes the urine to rise.

The urine is composed of *water* in the average proportion of 96 per cent., and of *substances dissolved* in it in the proportion of 4 per cent.

Among the "substances dissolved" in urine we find: urea, uric, hippuric, lactic, and oxalic acids, and ammonia; also creatin, chlorides, sulphates, phosphates, with the bases—potassium, sodium, calcium, and magnesium.

Urea ($CO[NH_2]_2$) is the diamide of CO_2; that is, a carbamide. Urea greatly prevails over the other constituents of the urine, since in normal urine it forms nearly one-half of the solids. Nearly one-half of urea is nitrogen. It is the principal representative of the waste of the nitrogenous tissues.

Urea is inodorous, fresh, bitter, neutral, very soluble in water and alcohol, but almost insoluble in ether. It crystallizes quickly into needles; slowly, into quadrangular prisms of the rhombic system. Urea fuses and decomposes at 248° F., with the development of ammonia.

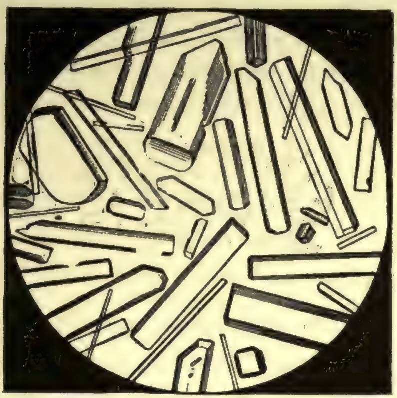


Fig. 167.—Urea from Human Urine. (FUNKE.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Urea is very rich in nitrogen. The nitrogen that finds its way from the body through the urine as a vehicle amounts to about 15 grams in twenty-four hours. This represents practically all of the nitrogenous waste of the economy, since less than 1 gram finds egress from all other channels taken collectively. The total amount of nitrogen is estimated by the Kjeldahl process.

Among the combinations with acids and bases of which urea is capable, those with nitric and oxalic acids are important. It is precisely these which are most commonly employed in the extraction of urea. With nitric acid, nitrate of urea is formed, which crystallizes in lozenge-shaped crystals. With oxalic acid, urea forms urea oxalate, and crystallizes into flat or prismatic bodies. Both types of crystals may very readily be demonstrated by placing crystals of urea beneath cover-glasses and allowing drops of nitric and oxalic acids, respectively, to flow beneath the cover-glasses. After some little time crystals of the respective types will be seen to form. Besides being free, urea is found combined in the urine with sodium chloride.

DECOMPOSITION OF UREA.—When urea is heated, vapors of ammonia are evolved. Urine is also subject to an *alkaline fermentation,* due to the micrococcus ureæ. This generally follows the acid fermentation, but may take place without it, in the bladder as well as outside. This fermentation is accomplished by decomposition of the urea into carbonate of ammonia. By virtue of this the urine is strongly darkened, becomes alkaline, putrescent, and forms a film of bacteria on its surface. Urinals always have an ammoniacal odor.

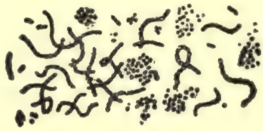
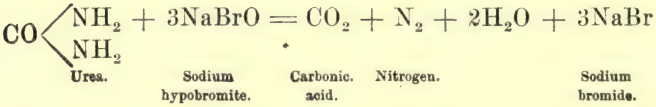


Fig. 168.—Micrococcus Ureæ. × 500. (After VON JAKSCH.)

Hypobromite of soda decomposes urea as follows:—



$$CO\begin{matrix}\diagup NH_2\\ \diagdown NH_2\end{matrix} + 3NaBrO = CO_2 + N_2 + 2H_2O + 3NaBr$$

Upon this reaction depends an estimation of the amount of urea present in a sample of urine. The calculation is made in units of nitrogen-gas, which gas rises in small bubbles to be collected and measured.

The constituents of urine are not actually formed in the kidney itself, as bile is formed in the liver, but are formed elsewhere. The kidney is simply the place where the constituents are picked out from the blood and eliminated from the body.

Muscular exercise has but a *slight* effect on the amount of urea excreted; this is in striking contrast to the quantity of carbonic acid that accompanies muscular exertion to find exit in the expired air. Muscle-work falls upon the carbon rather than upon the nitrogen of the muscle-substance.

QUANTITY OF UREA.—The quantity of urea excreted daily varies, but may be averaged as 500 grains. According to Tschlenoff, after a meal rich in proteids, which stimulate proteid metabolism, there are two maxima in its excretion. The first takes place at the third or fourth hour and the second at the sixth or seventh hour. The urea comes from proteid metabolism, and from the food. Labor greatly increases the exhalation of carbonic acid, but does not affect to any great extent the excretion of urea.

FORMATION OF UREA.—The chief source of urea is from the metabolism of the muscles. The ingestion of a large amount of proteid food stimulates metabolism. Muscles contain in their mass over 70 grams of creatin, while the amount of creatin excreted is only about 1 gram. Urine contains about 30 grams of urea and muscles only a trace. But all experiments to prove an actual relation between creatin and urea have been failures.

The other alloxuric bodies—xanthin, hypoxanthin, and uric acid—are also to be regarded. They are members of a group of bodies having as their base of formation the so-called purin-ring which consists of two urea radicles linked together by a central chain of carbon atoms. They are probably split up in part into urea.

I have already alluded to arginin as a source of urea. All the proteids are probably split up into bodies which form ammonia. Now, when we give by the mouth ammonia salts we find an increase of urea. Further, when ammonia salts are perfused through the liver we find that urea is generated. This leads us to believe that the liver is the chief manufactory of urea.

In Eck's fistula, when an artificial communication has been made between the portal vein and the inferior vena cava, the portal vein may be tied and the animal lives. After the Eck fistula the portal blood does not go to the liver, but goes to the vena cava. The hepatic artery is still sufficient to nourish the liver after Eck's fistula.

The diversion of the portal blood to the vena cava markedly diminishes the quantity of urea, whilst the ammonium salts in the urine are increased. This experiment supports the view that urea is formed in the liver from ammonium carbonate. In digestion I have alluded to arginin being converted into urea in the liver by the ferment, arginase.

Von Nencki has shown that the portal vein contains three to four times more ammonia salts than the hepatic vein or the hepatic artery. The ammonia comes from the breaking up of the proteids by trypsin into peptones, which, in turn, are broken up by erepsin into the amido-acids and ammonia.

The amido-acids are absorbed as such, and carried by the blood to the tissues. The amido-acids not used in tissue-building have their nitrogen split off rapidly without loss of energy and converted into urea, whilst the carbon residue is retained and utilized for the production of energy in place of an equivalent energy value of fat or carbohydrate. This decomposition takes place without that preliminary conversion of the food proteid into tissue, contrary to the usual prevalent view of Pflueger. (Abderhalden.)

It is not known how much urea is formed in the liver, but it is not far from half the amount of urea excreted. The intracellular ferments, which exist in nearly all the tissues, break up the proteids of lymph into ammonia, which is also converted into urea by the liver and by other tissues at present not known.

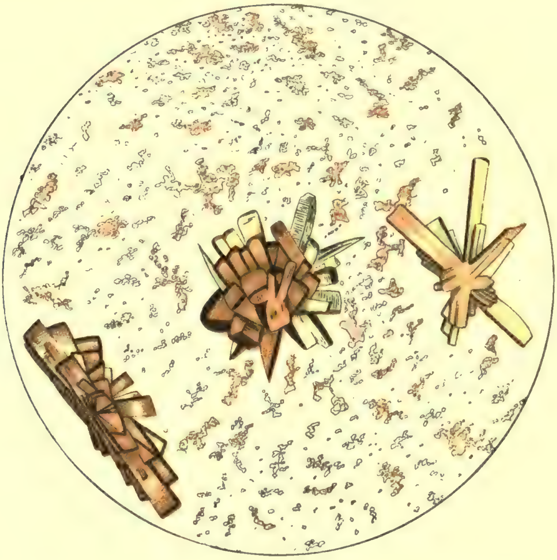


Fig. 169.—Uric-acid Crystals with Amorphous Urates. (PURDY, after PEYER.)

During sleep the amount of urea excreted remains nearly the same as when awake, but there is a diminution of carbonic acid exhaled and of oxygen inhaled. These results are due to muscular quietude.

Uric Acid ($C_5H_4N_4O_3$).—This constituent is scarce in human urine, hardly reaching 0.03 per cent. of its component solids. Next to urea, it is the product of excretion richest in nitrogen. It is very preponderant and perhaps altogether the chief excretion in birds, reptiles, and insects.

Uric acid, or lithic acid, is colorless, inodorous, and insipid; it usually crystallizes in whetstone crystals, which have for a fundamental type the vertical rhombic prism. It is insoluble in alcohol and ether, only very slightly soluble in water. The rhombic crystals are characteristic of uric acid.

If HCl be added to urine, there will be deposited on the bottom of the vessel after several hours a deposit resembling Cayenne pepper. Uric acid occurs in the urine as acid sodium urate. The HCl decomposes the urates, setting free the acid, which does not crystallize at once, by reason of the presence of phosphates. According to Liebig, it is especially by the phosphates that the acid is dissolved, under the form of urate.

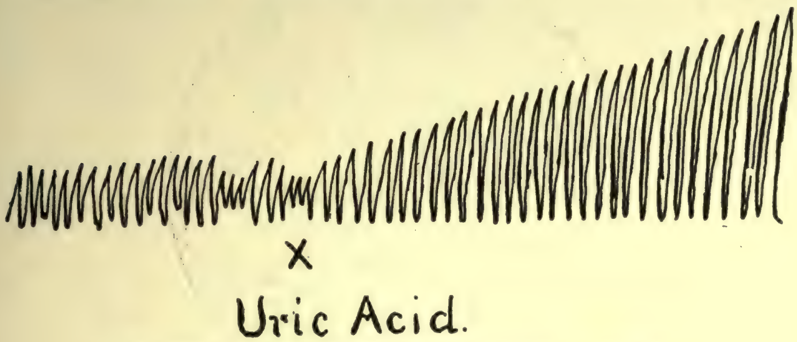


Fig. 170.—Uric Acid, Effect of on Intestinal Peristalsis.

Uric acid is *dibasic*, so that there are two classes of urates: the *normal urates* and the *acid urates*. The amorphous urates are quadriurates; acid urates are crystalline.

Uric acid is trioxy-purin. The purin bases are hypoxanthin, xanthin, adenin, guanin, and uric acid. All these bodies are derived from a substance called *purin*.

The elimination of nitrogen in the urine can be augmented by the food. Thus, nuclein (of which the thymus contains a large amount), coffee, cocoa, and meat (veal and ham especially), and beer are rich in purins. The bodies poor in purins are milk, potatoes, white bread, rice, eggs, salads and cabbage.

Formation of the Uric Acid.—It is a result in part of the breaking up of the nuclein of cells, forming xanthin, which by xanthin-oxidase is changed into uric acid.

Burian holds that hypoxanthin must be continually produced in the muscles, and that this production is increased by muscular contraction. Before it enters the blood it is converted by xanthin-oxidase into uric acid.

Uric acid has two origins, exogenous and endogenous. The exogenous origin is from the foods containing nuclein or purin substances.

The endogenous uric acid comes from the metabolism of all cells, but especially from the nuclein of the leucocytes; hence it is especially increased in the disease where there is an excess of leucocytes, leucocythæmia.

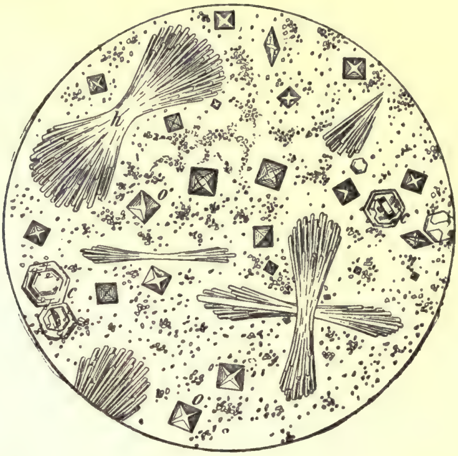


Fig. 171.—Urate of Soda and Crystals of Uric Acid (*h*), Oxalate of Lime (*o*), and Cystin (*c*). × 350. (LENHARTZ.)

Want of exercise leads to an increased formation of uric acid by a lessening of the oxidation of the tissues.

In gout the amount excreted in the urine is small, while it accumulates in the blood and tissues.

In the gouty deposits about the joints the so-called "chalk stones" contain 50 per cent. of sodium urate.

Uric acid probably circulates in the blood chiefly as a mononatrium urate or in combination with an organic acid.

Uric acid and lithic acid are the same. Lateritious, or brick-dust, sediment in the urine is composed of urates, and is chiefly sodium urate.

The average daily quantity of uric acid passed in the urine of man might be calculated at about 7 grains. When the quantity is excessive, it very frequently happens that the acid is deposited in the form of urinary calculi and gravel.

To increase the excretion of uric acid, the best means is to increase the secretion of urine by copious draughts of water.

MUREXIDE TEST.—Slowly and gently heat some urine and nitric acid in a porcelain dish to the point of dryness. Decomposition takes place, the color changing to yellow, and N and CO_2 are given off. After allowing the yellow stain to cool, add a drop of dilute ammonia-water to it, when there will be formed with the uric acid a purplish-red color of murexide. On the addition of caustic potash the color becomes a marked blue.

Hippuric Acid ($C_9H_9NO_3$), which, in the herbivora, is the principal representative of nitrogenized regression, is scarce in human urine. In the latter it appears chiefly after the use of some fruits, such as apples, plums, and grapes.

Hippuric acid is the product of the coupling of glycocin with benzoic acid. It may also be formed in the kidney itself. It is monobasic, very slightly soluble in cold water and ether, and readily soluble in warm water and alcohol. It crystallizes in vertical rhombic prisms, is of a bitterish flavor, and is acid in reaction. When decomposed by heating with acids and alkalies, or when transformed by animal ferments, hippuric acid resolves itself into its components: benzoic acid and glycocin. Ingested benzoic acid and oil of bitter almonds are eliminated with the urine as hippuric acid.

Some of the hippuric acid, at least, *is the product of the activity of the secreting cells of the renal tubules*, as is demonstrated by perfusing. If arterial blood containing benzoic acid and glycocin be forced through the blood-vessels of a freshly excised kidney, hippuric acid will be found in the perfused blood.

The food of herbivora seems to be an important factor in the manufacture of hippuric acid. When fed upon grain *without the husk*, hippuric acid is absent. Crystals of hippuric acid can be readily precipitated from the fresh urine of horses and cows.

Lactic Acid is a constant component of the urine. Its quantity is increased when it abounds in the blood from deficiency of oxidation, or from free derivation from the aliments, or from gastric fermentations.

Oxalic Acid is an inconstant component; it occurs with calcium in the crystalline form of octahedrons. The crystals are insoluble in acetic acid, but are readily dissolved by hydrochloric and nitric acids. The "envelope"-shaped crystals are very characteristic.

Oxalic acid appears to be derived from outside the economy, mainly from the ingestion of vegetable foods, as sorrel, lemons, rhubarb, etc. It may also result from incomplete oxidative processes.

Creatinin occurs in the urine in the average daily amount of 0.9 gram. Its sources are believed to be: (1) the creatin of muscles formed by the subtraction of a molecule of water and (2) flesh foods. If creatin be fed to animals it appears as creatinin in the urine; however, if it be injected intravenously it appears in the urine as creatin; so that it is very improbable that the kidneys are concerned in its manufacture.

Next to urea, it is the most important nitrogenous body in the urine. The absolute quantity of creatinin eliminated in the urine on a meat-free diet is a constant quantity, different for different individuals but wholly independent of quantitative changes in the total amount of nitrogen eliminated. The chief factor determining the amount of creatinin is the weight of the body and amount of fat it contains.

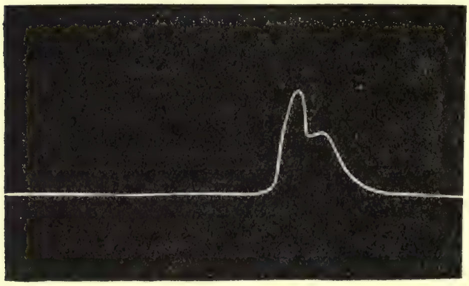


Fig. 172.—Effect of Xanthin on Muscle Curve, Causing an Extra Contraction during the Relaxation. (J. F. Ulman.)

Creatinin is the end-product of metabolism of muscle albumin. Creatinin, like uric acid, has an exogenous and endogenous origin, according to Folin. Creatinin is increased in fever. Creatinin is a measure of the physiological catabolism of muscular tissue. Xanthin, hypoxanthin, leucin and tyrosin, and traces of allantoin are sometimes formed in the urine, where they represent nitrogenized bases of albuminoid retrogression.

Ammonia.—The urine always contains a small amount of ammonia, on an average about half a gram. If you give carbonate of ammonia by the mouth it increases the urea, but not the ammonia in the urine. If, however, a more stable ammonia compound is given, as ammonium chloride or benzoate, then it is not converted into urea, but is excreted as chloride or benzoate or ammonium. The previous transformation of ammonia salts into a carbonate is a necessary condition for the ammonia to be converted into urea.

The body defends itself normally against the acids generated within it by proteid metabolism, by the ammonia which it produces.

The ammonium salts produced are inoffensive and are eliminated by the kidneys.

The quantity of ammonia in the urine varies with the food, being greater on a meat diet and least on a vegetable diet.

The introduction of acids into the organism incapable of conversion into carbonic by the organic oxidations increases the amount of ammonia in the urine. For the acid introduced combines with a part of the ammonia resulting from proteid metabolism, and, not being capable of transformation into carbonic, is excreted by the kidneys as an ammonium salt.

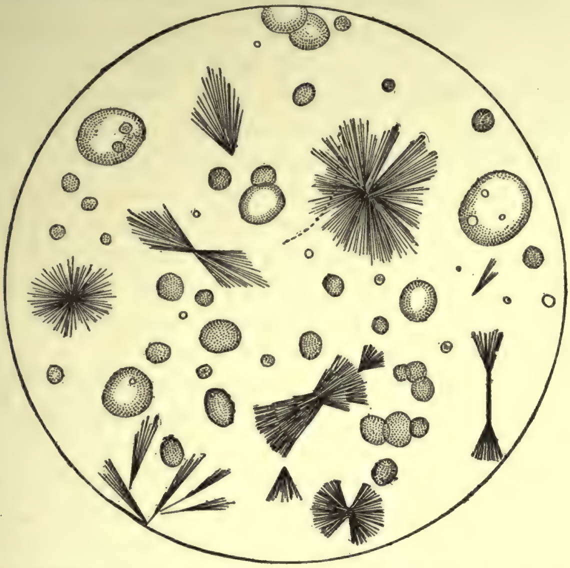


Fig. 173.—Leucin in Balls; Tyrosin in Sheaves. (Peyer.)

In this way we see the means by which the body resists poisoning by the acids generated within it. As long as the quantity of ammonia produced suffices to neutralize the acids, there is no trouble; but when the acids are in excess, as in the acidoses like diabetes, then there is a fall of temperature, difficult breathing, drowsiness, and collapse. The introduction of alkaline carbonates or salts of organic acids which are convertible into carbonic acid diminishes the amount of ammonia in the urine.

In the body, by the metabolism of the proteids, there are produced incombustible acids, chiefly sulphuric and phosphoric, which combine with ammonia to be excreted as such.

In serious diabetes there is an abundant production of organic acids not convertible into carbonic acid in the body. Such are the acetylacetic and beta-oxybutyric, which must be neutralized by bases, such as ammonia, which is derived from the meat used as food and from the proteid metabolism of the cells of the body. When this ammonia does not suffice to neutralize the acid, then the sodium of the blood is called upon; the blood becomes less alkaline. But the sodium of the blood is necessary to form a combination with the carbon dioxide for it to make its exit from the lungs.

Coloring Matters of the Urine.—The two main coloring matters of the urine are *urochrome* and *urobilin.* Under normal physiological conditions, urine may range from an almost colorless or pale straw-yellow through intermediate shades until reddish brown is reached. The commonest condition is yellow. Pale urine is usually of low density; high-colored, of high density, dependent upon the constituents excreted by the renal epithelium. In addition to the two main coloring matters may be mentioned *uroerythrin* and *hæmatoporphyrin;* these four are not the only chromogenic factors in the urine, but are the ones that are best known to us to-day.

UROBILIN, like bile-pigment, is an iron-free derivative of hæmoglobin. In normal urine it occurs in very small amounts and almost always as a *chromogen;* only rarely is it found free in physiological urine. In diseases it is commonly increased, especially in the highly colored urines of feverish patients. It gives to the urine a peculiar reddish color.

Urobilin is identical with stercobilin. The theory usually accepted concerning its mode of origin is that bile-pigment is converted in the intestines into stercobilin; while the major portion of the stercobilin leaves the body combined with the fæces, nevertheless some is *reabsorbed* and excreted in the urine as urobilin. Some observers state that intestinal micro-organisms can reduce bilirubin to urobilin.

UROCHROME is regarded as the proper pigment of the urine, giving to this secretion its familiar yellow color. When removed from this medium the urine loses nearly all of its color. It is separable into yellow scales. Urochrome may decompose to produce *uromelanin,* among other products. The last-named constituent gives a blackish tinge to the urine.

UROERYTHRIN.—Aqueous solutions of urochrome, when exposed to the air and so oxidized, turn red (uroerythrin). This coloring matter is familiarly known by reason of its association with the acid sodium urates, which it colors red to form the popularly known "brickdust" sediment. Normally, it occurs in but small quantities, but by reason of its strong coloring properties is intimately concerned in the coloring of the urine.

Three properties are characteristic of uroerythrin: (1) its remarkable affinity for uric-acid compounds, (2) the ease with which its solutions are decolorized by light, and (3) its color-reactions with caustic alkalies and mineral acids.

HÆMATOPORPHYRIN exists in but very small amounts in the urine normally; pathologically and after the ingestion of certain drugs, as sulphonal, it may be greatly increased.

INDICAN, OR INDOXYL.—This is another pigment which colors the urine intensely yellow. It is an indigo substance represented by a dense, yellow-brown acid, nauseatingly bitter and very soluble in water, alcohol, and ether.

Indican is derived from *indol*, which is formed in the intestines as a product of putrid decomposition of the pancreo-peptones. It is in direct relation to the quantity of bacterial putrefaction of albumins. Indican is really a conjugated indoxyl sulphate of potassium.

Test.—When urine is mixed with an equal bulk of strong HCl, indoxyl is liberated from the sulphate. A solution of hypochlorite is now added, drop by drop, when indigo-blue will be formed by oxidation of the indoxyl. Upon the addition of chloroform the blue matter is precipitated, forming a layer at the bottom of the liquid.

Pathological Pigments.—BLOOD-PIGMENTS.—Blood in the urine (hæmaturia) may result from injury or disease anywhere along the urinary tract. In this urine the red blood-corpuscles are found in the deposit. An idea as to the probable source of the hæmorrhage may be gotten by careful analysis. Thus, blood from the *kidney* is usually small in amount, gives urine a "smoky" appearance, and is well mixed. Large coagula are never found in this urine. In hæmorrhage from the *ureter* it is common to find long, wormlike coagula. *Bladder* hæmorrhage is known by its numerous clots and shriveled-up leucocytes. If the urine be alkaline, crystals of triple phosphate will likely be found.

In *hæmoglobinuria*, the pigments exist *in solution*, no corpuscles being found. It is caused by the excretion of hæmoglobin by the kidneys when it exists as a free body in the blood-stream. Free hæmoglobin is due to active hæmocytolysis, which is produced by the injection of foreign blood, severe burns, etc.

BILE-PIGMENTS IN THE URINE.—It is usually in cases of icterus that this condition exists when the urine becomes of a decided yellow color. The pigment usually found is bilirubin.

Bile-pigment is readily detected by Gmelin's reaction, performed by gently pouring the urine upon the surface of fuming nitric acid, when a green-colored ring appears.

CARBOLURIA.—In this condition the urine is greenish brown, becoming darker upon exposure to the air. It occurs either after poisoning by carbolic acid or when the acid has been administered as a drug.

DRUG-PIGMENTS.—After the administration of certain drugs the urine is sure to be colored differently from normal. Those which do this are rhubarb, hæmatoxylin, santonin, and methylene blue.

The Inorganic Constituents.—These are derived either from the aliments with which they are introduced into the body or they are formed in the organism by combination with bases of the oxidized sulphur and alimentary phosphorus. They are eliminated with the urine in daily amounts from 16 to 24 grams.

To these components belong: *chlorine,* combined chiefly with sodium; *phosphoric acid,* uniting with potassa, soda, calcium, and magnesia to form basic, neutral, and acid salts; *sulphuric acid,* in part combined with alkalies and in part united to indol and phenol in the form of aromatic substances (Baumann). The chlorides and the major portion of the phosphates come from the blood; the sulphates and the remainder of the phosphates from the activities of metabolism.

CHLORIDES occur in the form of sodic chloride. The average quantity excreted is 180 grains daily. If the chlorides be in excess in the food, not so much is given out in the urine as has been introduced, since part passes off through the skin and rectum, while another part accumulates in the tissues. Some is decomposed to form the HCl of the gastric juice. Sodium chloride is absent in early stages of pneumonia.

PHOSPHORIC ACID.—This acid, combined to form the alkaline (sodium and potassium) and earthy (calcium and magnesium) phosphates, appears in the urine in the daily quantity of about 2 grams. The phosphoric acid of the urine is derived principally from the alimentary phosphates.

Hence there is an increase of phosphates after a meal composed principally of meat, after muscular and nervous labor. There is pathological increase in diseases of the brain and in osteomalacia;

there is diminution in pregnancy by reason of deposition of phosphate within the fœtal bones.

THE SULPHURIC ACID is derived from the liberation and oxidation of tissue sulphur. Sulphuric acid occurs in the urine in combination with alkalies, principally sodium and potassium. The sulphur introduced into the system medically finds egress mainly in the fæces, as it does not easily pass into the blood. From this it is inferred that the sulphur eliminated is derived especially from the transformation of the tissue-proteids. It runs parallel with urea excretion. The daily quantity of sulphates excreted is 3 grams. Proteid contains 1 per cent. of sulphur and 16 per cent. of nitrogen.

The aromatic or conjugated sulphates form one-tenth of the total sulphates, and arise from bacterial putrefaction within the intestinal canal, in intestinal obstruction, typhoid fever, etc. The chief aromatic (ethereal) sulphates are phenol sulphate of potassium and indoxyl sulphate of potassium.

CARBONIC ACID in a state of combination is scarce in the urine and only increases there after the use of alkaline carbonates and of vegetable acids, which latter are transformed into carbonic acid by oxidation.

To sum up in an approximate average the very variable proportions of the principal, normal constituents of the urine, it may be said that with a mixed diet and moderate bodily movement there are in every 100 cubic centimeters of daily urine:—

Water	96.00	grams.
Solid components	4.00	"
Urea	2.30	"
Uric acid	0.03	"
Sodium chloride	0.80	"
Phosphoric acid	0.15	"
Sulphuric acid	0.20	"
Earthy phosphates	0.08	"
Ammonia	0.04	"

Fermentation of Urine.—We have seen that the reaction of urine is generally acid; but it can become alkaline, even in the physiological state, from abundant ingestion of alkalies, or of salts with organic acid. The intensity of the acid or alkaline reaction of urine must necessarily vary, not only with the proportion of the components that determine it, but also with the degree of dilution.

The acidity of the urine may, however, be further increased by a process of *acid fermentation* due to bacteria, in the presence, perhaps, of vesical mucus. This fermentation may take place outside of the bladder as well, for we see that the acidity of the urine continues to increase from the time of emission.

The process of acid fermentation is finally accompanied with development of a mycelium whose spore is smaller than that of a torula. It appears that with the initiation of this process the urine absorbs oxygen much more actively (Pasteur).

The urine is also subject to an *alkaline fermentation* due to an enzyme, *urease*, of the micrococcus ureæ. It generally follows the acid fermentation, but may occur without it, in the bladder as well as outside. The urine, after prolonged exposure, especially in a warm atmosphere, has been found to become neutral and then gradually alkaline. This fermentation is accompanied with decomposition of the urea into ammonium carbonate, by which the urine is strongly darkened and becomes alkaline and of a strong, putrid, ammonical odor.

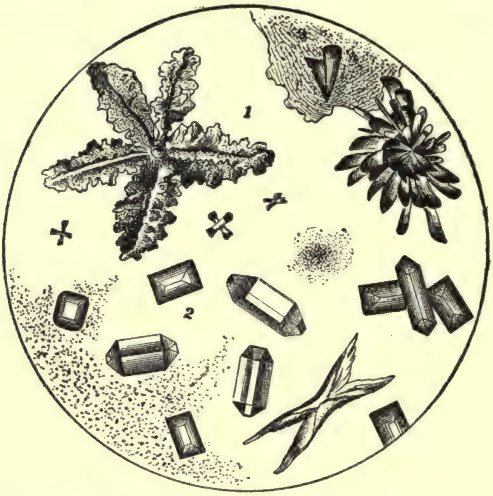


Fig. 174.—Crystals of Ammonio-magnesium Phosphate. (After Ultzmann.)

1, Crystals in rosette shape. 2, Crystals in coffin-lid shape.

In disease of the urinary apparatus, and especially in vesical inflammation and catarrhs, the process of ammoniacal fermentation is already advanced in the urine at the time of its passage. In this case, epithelial mucus and purulent elements aid in making it turbid.

On the basis of the preponderance of one group of combinations over another, they are divided into *uric, oxalic,* and *phosphoric sediments.*

URIC SEDIMENTS.—These, composed of uric acid and the alkaline and earthy urates, increase the acidity of the urine, render it muddy, and impart to it a brick-red color, which is made more intense by exposure to the air. With the microscope the observer recognizes in the sediment the characteristic crystals of uric acid.

The precipitation of urates within the bladder is very probably caused by concentration from the absorption of water from the urine. The common belief that holding the urine predisposes to stone is, therefore, justified. Another and more frequent cause of uric sediments in the bladder is the acid fermentation which may occur there from the presence of mucus, as in vesical catarrh. These are strong predisposing causes to uric calculi.

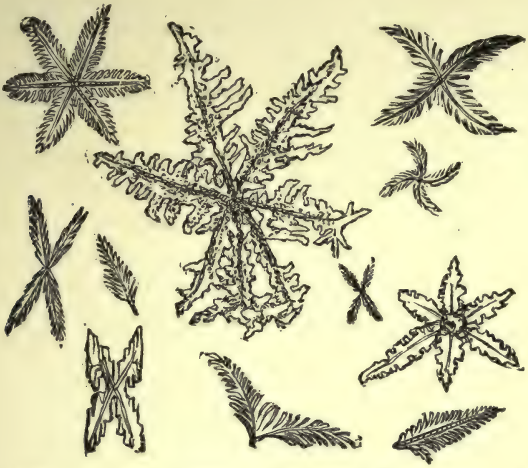


Fig. 175.—Feathery Crystals of Triple Phosphate. × 350. (After TYSON.)

OXALIC SEDIMENTS.—These accompany the uric sediments, but there may be a predominance of oxalic acid combined with lime. This sediment is recognized by its crystals of calcium oxalate, the "envelope" crystals. They are insoluble in acetic acid.

They are chiefly observed in deficient respiration, in rickets, in epileptiform convulsions, and in convalescence from serious diseases. The crystals are precipitated by *neutralizing the acid urine.* This explains why uric calculi are often mixed with oxalic sediments. The acid urine, with its uric sediment, readily becomes neutral and alkaline by reason of purulent catarrh with, therefore, succeeding precipitation of the oxalates.

Phosphoric Sediments.—The phosphoric sediments consist chiefly of crystallized ammonio-magnesium phosphate, coffin-lid shaped crystals, and of calcium phosphate.

The phosphoric sediments are readily distinguished by the alkaline reaction of the urine and by their insolubility by heat (by which the urates are dissolved), and phosphoric crystals are distinguished from oxalic by their *solubility* in acetic acid.

The phosphoric sediments acquire importance only when they are formed within the bladder, either by purulent products or by excessive retention of urine, as in paralysis.

Sediments in Urine.—Acid Urine.—*Uric Acid.*—Rhombic prisms, square plates, cubes, ovoids or rosettes, or whetstone or dumb-bell crystals.

Urates.—Brick-dust or lateritious sediment, irregular amorphous granules of a brownish or pink color. They are composed of sodium acid urate and potassium acid urate. They dissolve when urine is heated.

Calcic Oxalate.—In octahedral crystals, or envelope crystals, or dumb-bell crystals. They are insoluble in acetic acid and soluble in hydrochloric acid. Cystin appears in six-sided tablets having an opalescent luster or four-sided square prisms lying separately. Rare.

Leucin appears in yellowish, highly refracting spherules. Rare.

Tyrosin appears in fine, colorless needles arranged in sheaf-like collections or rosettes. Rare.

Neutral *calcium phosphate crystals* of colorless needles, which group themselves with points in a common center. Rare.

Sediments in Alkaline Urine.—1. Amorphous. Earthy phosphates; fine granules dissolving in acetic acid without evolution of carbon dioxide.

2. Calcium carbonate in two shapes: (*a*) fine granules soluble with effervescence in dilute acetic acid; (*b*) dumb-bell or spheroidal masses, dissolving in dilute acetic acid with evolution of carbon dioxide; rare.

3. Acid ammonium urate. Pigmented spheres, which dissolve in hydrochloric acid and then crystals of uric acid separate.

4. Ammonium-magnesium phosphate. Coffin-lid crystals.

Albumosuria.—In cases of osteomalacia, albumoses are found.

Peptonuria.—In the stage of resolution of pneumonia and in cases of suppuration, the breaking up of the leucocytes or pus-corpuscles produces a peptone, or, more correctly, a deutero-proteose, which appears in the urine.

Exceptional or Pathological Components.—Besides the ordinary constituents of the urine, there may at times be found in it exceptional ones of pathological significance.

ALBUMIN.—Albumin, and more properly *albumin of blood-serum,* is an abnormal component of the urine which has great importance for the physician. Its presence in this secretion gives the clinical condition commonly termed *albuminuria.* Its presence is due to a great number and variety of causes, a few of which are: (1) temporary or lasting increase of pressure of the blood within the renal system, especially hyperæmia from cardiac defect; (2) exanthemata (scarlatina), and febrile diseases in general (pneumonitis, typhus, pyæmia); (3) inflammation and degeneration of the kidneys, as well as disturbances and inflammation of the brain and epilepsy; (4) any substance which acts upon the vascular system of the kidneys, such as diuretics, mercurials, and cantharides.

The *recognition* of albumin in the urine requires care, and, above all, it is necessary to remember some of the reactions that occur in the urine. If the urine be acid, the albumin accidentally contained there coagulates at temperatures above 70° C., the coagulation first showing as an opacity upon the surface of the liquid.

Again, if the urine be alkaline and then subjected to heat, there may result a marked opacity without the presence of albumin, the darkening being caused by precipitation of phosphates. To differentiate from phosphates, a few drops of acetic acid are added, which immediately dissolve them.

Heller's Nitric-acid Test.—Albumin is also recognized by means of adding one-fourth of the proper volume of HNO_3. The reaction, a ring of white precipitate occurring at the junction of the two liquids, is evident when there is much albumin. If, instead, the quantity should be small and the urine concentrated, nitrate of urea will be precipitated, giving an erroneous impression to the observer. If the urine be diluted one-fourth with water, the urea precipitate disappears.

A method of *measuring* the quantity of albumin present in urine is easily accomplished by the method devised by Esbach. The essential principle is precipitation of the albumin by means of Esbach's reagent, which in 1000 cubic centimeters of water contains 10 grams of picric acid and 20 grams of citric acid. This is performed in a test-tube so graduated that the figures represent *grams* of *dried albumin* in a *liter* of *urine.* It is essential that the reaction be allowed to proceed for twenty-four hours before any readings are taken.

Proteoses are detected by the precipitates produced by nitric and salicyl-sulphonic acids clearing up on heating the urine and returning on cooling.

SUGAR.—While it is known that normal urine may contain traces of sugar, attention is required with the sugar that occurs in excess, especially from the disease known as diabetes mellitus.

In the first place, diabetic urine is abnormal in amount, even reaching 10 liters a day. It has a high specific gravity, and is of a pale and greenish yellow, so that sugar may be suspected at once; when the increased density is due to urea the urine is intensely reddish. However, it must be remembered that the nitrogenous excreta are also increased.

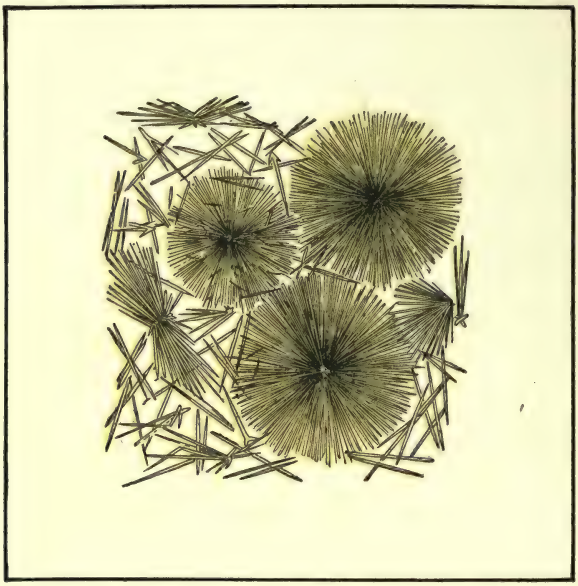


Fig. 176.—Crystals of Phenylglucosazone. (PURDY, after V. JAKSCH.)

The sugar present is in the form of *dextrose,* or grape-sugar. It is increased with a carbohydrate diet and diminished with one that is nitrogenous. Upon standing, there are developed in diabetic urine *torulæ.*

Fehling's Test.—Results are obtained by the use of Fehling's solution. This is an alkaline solution of copper sulphate to which

Rochelle salt has been added. The latter holds the cupric hydrate in solution. The presence of sugar is denoted by the reduction on boiling of yellow precipitate of cuprous oxide.

Phenylhydrazin Test.—This is, perhaps, the most trustworthy of all the sugar tests. It depends upon the formation of a very characteristic body from phenylhydrazin hydrochloride and sodium acetate: *phenylglucosazone.* The resultant body is found as yellow crystals, for the most part arranged in rosettes and clusters. They are only sparingly soluble in water. The characteristic crystals are readily detected under the microscope.

The phenylhydrazin test takes place with glucose, lævulose, and glycuronic acid.

Fermentation Test for Sugar.—With an Einhorn saccharometer tube introduce a definite quantity of urine and a piece of Fleischman's yeast about the size of a pea; then stand in a warm place. Next morning read off the percentage of glucose on the instrument. The fermentation test of glucose excludes glycuronic acid, as it will not ferment.

BILE and BLOOD in the urine have been previously discussed.

TUBE-CASTS.—Cylinders, or casts, of the uriniferous tubules are of prime importance to the physician in his diagnosis of some forms of renal disease. Those which are straight may be said to be casts of the collecting tubes; the more curved and twisted ones are probably from the convoluted tubules. Various kinds of casts, or cylinders, are distinguished.

Theory of the Urinary Secretion.

The theory of the urinary secretion is summed up by regarding the water (which determines the quantity of the urine) and its salts as a product of filtration from the renal glomerules; the dissolved components (as urea, uric acid, etc.) as products of the special activity of the elements of the epithelium of the contorted tubules.

That the passage of the water takes place chiefly by filtration is shown by the fact that the quickness of this passage is kept in direct relation with the pressure of the blood in the renal arteries, and the glomerules in particular, from whose vessels the watery element of the urine is chiefly derived.

Nevertheless, hydrostatic pressure is not the only factor at work in the glomerules, for their epithelium exerts both a positive and negative influence: positive in that some of the salts of the urine are here secreted; negative, in that the serum-albumin of the blood is prevented from passing through.

In support of the part that blood-pressure bears to secretion it has been noted that, when the total contents of the vascular apparatus are increased so that blood-pressure also increases, there follows an increased secretion; that increased action of the heart increases the amount of urine; and that variations in the caliber of the renal artery give proportionate urinary secretions.

The *diuretics* made use of by the physicians owe their efficiency mainly to these principles. Digitalis increases the quantity of urine by raising blood-pressure, whereas urea, potassium nitrate, caffeine, etc., act upon the rodded epithelium of the tubuli contorti.

It must not be forgotten that at all times there is glomerular pressure by reason of the vasa efferentia being of smaller lumen than that of the afferentia.

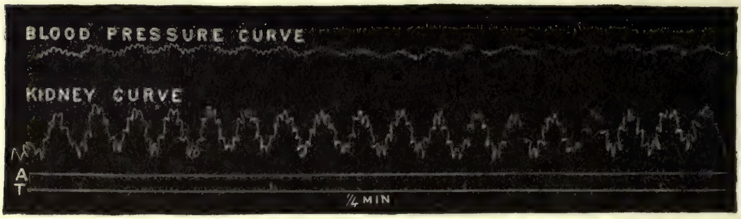


Fig. 177.—(STIRLING, after ROY.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

Kidney curve, Curve of the volume of the kidney. *T*, Time-curve; intervals indicate a quarter of a minute. *A*, Abscissa.

Colheim and Roy, in their experiments with the oncometer, have noted that the curve representing the volume of the kidneys runs parallel with the curve of arterial pressure; it has smaller oscillations, both respiratory and cardiac. The nervous influences acting upon the renal secretion are *vasomotor;* existence of the so-called secretory nerves has not yet been definitely demonstrated.

Toxicity of the Urine.—After the ablation of the two kidneys the animal dies from uræmia; that is, there is an accumulation of the urinary products in the blood. The removal of one kidney is not necessarily fatal. The urine of daytime is more toxic than that at night; it is especially narcotic, while night urine is more convulsivant. A man excretes enough poisonous material by the kidneys in two days to cause death. When there is an excess of urea in the blood, the disease is termed uræmia. The toxic substance is probably not urea, but some other organic body. The usual cause of uræmia is Bright's disease. Uric acid in excess is supposed to be the cause of rheumatism and gout.

Influence of the Nerves Upon the Secretion of Urine.—As has been elsewhere stated, the nerves of the kidneys are derived from the renal plexus and are composed of both medullated and non-medullated fibers with nerve-cells. These are both vasodilator and vasoconstrictor in function. As yet, no true secretory nerves are known, so that it is by the influence of the vasomotor nerves distributed along the course of the renal vessels that variations in the amount of urine secreted occur. Thus, the amount of urine secreted depends upon the pressure of the blood circulating through the capillaries.

Frequent and small urinations, under mental apprehension, show a very probable nervous influence upon the excretion of the urine. Polyuria and the peculiar aspect of the urines of hysteria are also known; whether these peculiarities are dependent upon direct nervous influence upon the secretion is not known. Ludwig believes that the cause lies in the increased pressure in the renal arteries from spastic contraction of other vascular regions.

Injury by puncture of the vasomotor center in the floor of the fourth ventricle likewise is followed by polyuria, accompanied by hæmaturia and albuminuria. By this experiment it is demonstrated that variations in urinary secretion are, for the most part, very intimately concerned with vasomotor innervation.

If, while the renal vasomotors are paralyzed, the majority of the vasomotor nerves of the entire body be also paralyzed (as by section of the medulla), there follows a general dilatation of the arterioles and capillaries of the body. This causes such a decided fall in the blood-pressure that the amount of urine secreted is much diminished or entirely absent.

However, secretion is not suspended by removal of the brain, nor destruction of the spinal cord below the cervical portion, provided that the medulla is intact and with it the respiration and circulation. (Krimer.)

Urinary Excretory Apparatus.—After the urine has been secreted by the kidneys, it must needs be carried away from the body, so that the economy may not suffer from resorption of contained toxic principles, as well as not to interfere with the renal action by equalizing pressure *within* that organ from damming back of the urine.

The excretory apparatus comprises the *ureters, bladder,* and *urethra.*

The Ureters are two cylindrical membranous tubes of the diameter of a goose-quill and about fifteen inches long. They extend from the pelvis of the kidney to the bladder, to which viscus runs the urine from the kidneys. The general course of each ureter is downward and inward toward the median line, to empty into the base of the bladder by a constricted, slitlike orifice. The ureter runs for nearly an inch between the muscular and mucous coats of the bladder before it makes its exit upon the inner wall of the organ.

Structure.—The ureter is composed of three coats, or layers: *serous,* or *adventitia; muscular;* and *mucous.*

The *adventitia* is continuous with the capsule of the kidney at one end and with the fibrous layer of the bladder at the other. In it are found its larger vessels and nerves.

The *muscular coat* comprises the two usually distinct muscular layers: an external longitudinal; an internal, circular one.

The *mucous coat,* continuous with that of the bladder, lines the ureter. It is composed of stratified epithelial cells.

Movement of the Urine.—The urine flows into the tubules by the *vis-a-tergo* pressure of the blood in the afferent capillaries. This averages from 120 to 140 millimeters of mercury. This force, which is capable of making the urine flow through the tubules, is incapable of forcing the urine through the ureters. By reason of the ureters taking a diagonal course through the vesical wall, the weight of the urine already in the bladder must exert a certain amount of pressure upon this portion of each ureter. To overcome this some auxiliary force must be called into action, which is the peristaltic contraction of the ureters. This movement begins at the kidneys and is transmitted (with a speed of from 20 to 30 millimeters per second) downward into the bladder. With the completion of each peristaltic movement there exudes into the bladder a drop of urine. The movements of the two ureters are not synchronous; they are reflex, being caused by the presence of urine in the lumen of the ureter.

In a case of Dr. W. Easterly Ashton's, where the ureters opened on the abdominal surface, I counted an emission of urine by the ureter every twenty-four seconds.

The greater the distension of the lumen of the ureter, the more rapid will the number of peristaltic movements become.

Experimentally, peristaltic movements may be aroused by electrical or mechanical excitation; movements always begin at the point excited and proceed toward both ends.

The Urinary Bladder.—The bladder is a musculo-membranous pouch which serves as a temporary reservoir for the urine. It lies behind the pubis and within the pelvic cavity while the viscus is empty, but when distended it protrudes into the hypogastric region, in extreme cases even up to the umbilicus.

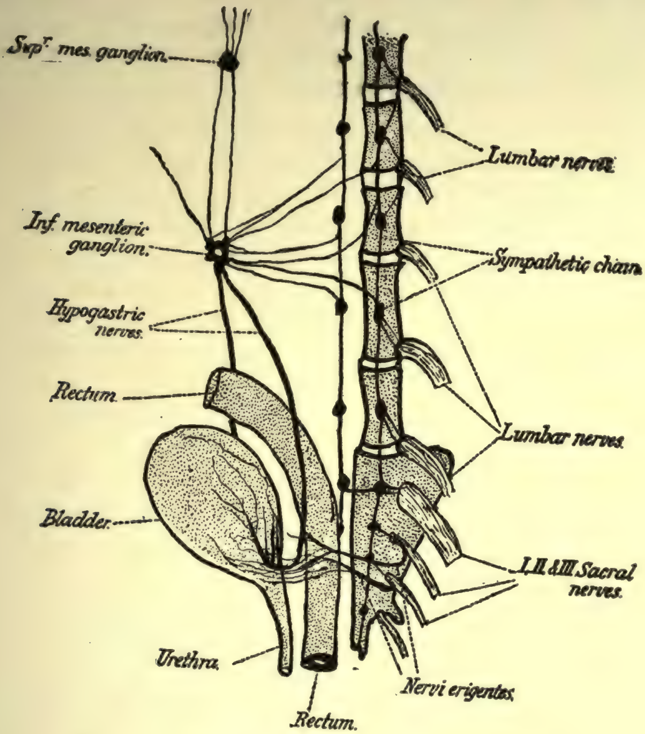

Supʳ mes. ganglion.
Lumbar nerves
Inf. mesenteric ganglion.
Sympathetic chain
Hypogastric nerves.
Rectum
Lumbar nerves
Bladder
I. II. & III. Sacral nerves.
Urethra
Nervi erigentes
Rectum.

Fig. 178.—Diagram of Nerve-supply to Bladder. (Nawrocki, Skabitchewsky, and Starling.)

In the cat, two days after section of the spinal cord above the vesico-spinal center, I found that a pressure of 140 millimeters of water was required to overcome the tonus of the sphincter when a cannula was bound in the urethra.

Micturition.—When the act of micturition takes place the spinal detrusor center is excited into activity by the pressure of the urine; the sphincter reflex center is also independently excited by the pressure of the urine, and opens to expel the secretion. The spinal detrusor and spinal sphincter are under the control of a cerebral detrusor center which I have shown to be seated in the locus niger, and which is set in activity by the cerebral hemisphere in voluntary micturition. The detrusor center sends its impulses down the lateral columns of the spinal cord to the vesico-spinal center.

Voluntary micturition is materially aided by the action of the abdominal and respiratory muscles.

CHAPTER IX.

METABOLISM.

THE food which has been properly digested within the stomach and intestines is absorbed by the chyle vessels and by the small capillaries, whose union forms the portal vein. When once in the blood-stream, it circulates with the blood-current, which carries it to all of the various organs and tissues of the body. The absorbed nutritive products are held in solution within the plasma of the blood.

In order to nourish the structures outside of the vessel-walls, the plasma, with its contained nourishment, is constantly being passed through the capillary walls into the spaces between the living cells. By this provision each cell is bathed in a plentiful supply of lymph, from which medium it absorbs its nourishment.

The various stages of the nutritive process—viz., the transudation of the nutritive plasma from the blood, the assimilation of parts of this by the tissue under repair, the absorption of the other portion by the lymphatics, and, last, the reabsorption of the final residue together with that of the waste products of the tissues by the veins—are performed simultaneously and continuously in the living body. With the entire organism in a healthy condition there is a perfect balance of action.

Action and use are always followed by a corresponding amount of waste. The machinist must be making repairs to the locomotive or other machine that is in use. So the tissues of the body are continually being destroyed, to pass away as effete matters, due to exercise and action of the various organs of the economy. Thus, the simple movement of the finger, our very thoughts and reasonings, are productive of waste in the tissues concerned.

It is due to the repair by the machinist that the machine is kept in normal running order; likewise it is to the proper absorption, assimilation and elimination of foodstuffs taken into our own economies, that the body owes its normal function and health.

The digested products, having arrived at their destination in the organs and tissues, undergo two kinds of chemical processes in the presence of oxygen, and under the peculiar activity of the cells. The one is *anabolism,* or upbuilding; the other *catabolism,* or destruction. These two processes are diametrically opposite to one another, so that by virtue of the one the organism increases in bulk; by virtue of the other its bulk is diminished.

By reason of the *anabolic* processes, the nonliving materials of the food are converted into the complex molecules of the living tissues, where they are stored up to form a store of potential energy. At any time the organism is capable of transforming this potential energy into *kinetic,* which is usually most conspicuous to the observer as heat and motion.

By this transformation, the complex tissues are broken down into excretory products whose structure is simple. The waste materials leave the cells to be carried by the lymphatics into the blood-stream, ultimately to reach the exterior of the body, as excreta or as components of some secretions.

The two processes, anabolism and catabolism, taken conjointly, constitute what is known as *metabolism*: an exchange of material.

Normal metabolism thus requires the ingestion of a suitable quality and quantity of food, which must be absorbed, assimilated and stored within the tissues. In the latter place there must occur the necessary transformation of the food in its now complex form, into simpler products of an effete nature, evolving, at the same time, those functions and activities which are common to the organism. In short, all of the physiological phenomena demonstrable in the economy are the result, either directly or indirectly, of anabolic or catabolic changes.

Anabolic processes become visible during (1) the growth of the body in infancy and adolescence, and (2) during convalescence from a serious and debilitating disease.

Catabolic processes become evident during old age and in the course of malignant diseases. *Catabolism* is the destruction of tissue, from which process result the numerous manifestations of life.

1. DUPLICATION: That is, the decomposition of an organic substance into two or more products whose sum represents exactly the primitive substance.

2. DEHYDRATION: This is a particular form of duplication in which one of the products is water.

3. OXIDATION: This is the most important part of the chemical processes. By this means the decomposition is accomplished with fixation of oxygen, such as the decomposition of albumin, sugars and fats.

There is not a direct oxidation of the complex foods or tissues, for these bodies undergo cleavage into simpler substances. It is these cleavage substances which are oxidized. Oxidation is a chemical process presided over by intracellular ferments, specific in their nature, as they act only upon particular chemical groups. The enzyme first acts, then the resultant products undergo oxidation.

4. Deamidization: A liberation of the NH_2 group.

5. Synthesis: This is the combination of two or more substances whereby result a third, new substance. Syntheses are characteristic of anabolism, but they do occur in *catabolism.* Thus, with the disintegration of the tissue elements into benzoic acid and glycocoll, there follows hippuric acid; urea is formed from carbonic acid and ammonia.

The energy produced by the metabolism of materials in the body can be measured by the number of calories. Heat and work represent the end results of metabolism. The splendid apparatus of Atwater has accomplished calorimetric results for man hitherto unattainable.

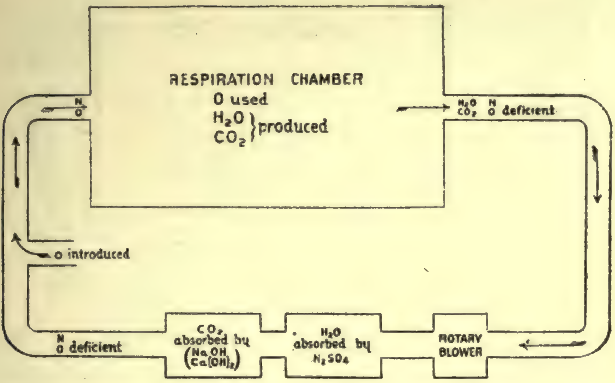

RESPIRATION CHAMBER
O used
H_2O CO_2 } produced
N O
H_2O CO_2 N O deficient
O introduced
N O deficient
CO_2 absorbed by ($NaOH$ $Ca(OH)_2$)
H_2O absorbed by N_2SO_4
ROTARY BLOWER

Fig. 178*a*.—Schematic Outline of Ventilation System in the Respiration Calorimeter at Wesleyan University, Middletown, Conn. (Benedict.)

The end results of metabolism are thrown off by the lungs, skin, intestines and kidneys.

Foods burned within the body produce the same amount of heat as when burned outside the body, according to Rubner and Atwater.

Catabolism varies according to the age and weight of the animal; the younger and lighter the animal, the greater is the relative destruction of proteid.

Peptones and albumoses have about the same caloric and nutritive value as the proteids.

Respiration Calorimeter.—I follow the description of it by Benedict. The apparatus at Middletown in its present form permits of the measurements of the carbon dioxide and water vapor elimination, and oxygen consumption, as well as the heat production, and it was believed that the first extended use of the improved apparatus would best be a study of inanition.

The apparatus has been described in detail in *Publication of the Carnegie Institution of Washington,* 42.

"Since the apparatus and technique are not familiar to many, it may be advisable to consider for a few moments some of its salient points. The name 'respiration calorimeter' has been given this apparatus by Professor Atwater to indicate that it measures both respiratory products and heat output.

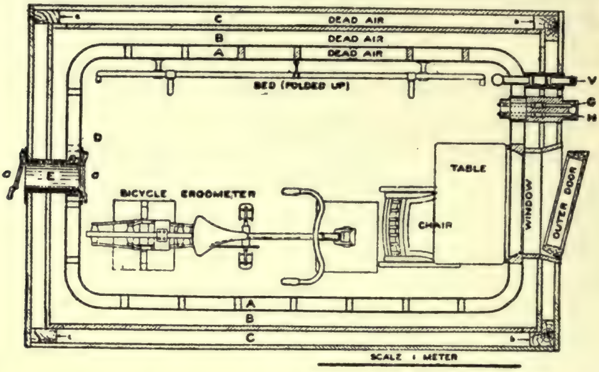


Fig. 178*b*.—Horizontal Section of the Respiration Calorimeter. (Benedict.)

▬ Portions shaded thus are of wood. *A*, Dead air space between Cu and Zn walls. *B*, Dead air space between Zn wall and inside wood wall. *C*, Dead air space between inside and outside wood walls. *D*, Pneumatic air and heat insulation packing. *E*, Food aperture tube. *o o*, Air-tight ports (glass). *G*, Outcoming water. *H*, Ingoing water for absorbing heat. *V*, Ventilating air current.

"Considering first the respiration features of the apparatus, it may be said that the chamber itself consists of an air-tight copper box, through which a ventilating current of air is caused to pass by means of a rotary blower. This ventilating air current leaving the chamber contains carbon dioxide and water vapor, and the oxygen content is somewhat diminished. The air is purified by first passing it through sulphuric acid to absorb the water vapor, and second, through soda lime to absorb carbon dioxide. The deficiency of oxygen is made up by admitting oxygen from a cylinder of the highly compressed gas. The air current is then caused to return to the chamber and is used again. By making proper provision to note the increase in weight of the sulphuric acid and soda lime vessels, the quantitative amounts of water vapor and carbon dioxide given off by the subject may be readily determined; and further, if the loss in weight of the oxygen cylinder is recorded, the amount of oxygen absorbed may be determined. Numerous incidental corrections are necessary for unusual accuracy in these determinations, but the principle is fundamentally that just outlined.

"For measuring the heat, the apparatus as a calorimeter must next be considered. The inner chamber of copper is surrounded by three walls, one of zinc, and two of wood. With the intervening air spaces between these walls, the construction is not unlike that of a refrigerator, and hence heat insulation is secured. When a man enters a chamber constructed on this principle, the insulation is so perfect that soon the temperature resulting from the heat production in the body would become unbearable. As houses are heated in winter by passing hot water through pipes, this small house or individual room is cooled by passing cold water through pipes or heat absorbers. Special electrical connections prevent any loss of heat from the walls, and by noting the quantity of water passing through the heat-absorbing system, and the temperature through which it is warmed, the measurement of heat is readily made."

Effect of Food on Respiratory Exchange.

There is an increase of respiratory exchange that is the intake of O and outtake of CO_2 in all cases after the taking of food. The gaseous exchange is most markedly elevated in the first two hours, which diminishes four to five hours after breakfast.

Fat causes a 10-per-cent. increase in the respiratory exchange, proteids a rise of 30 per cent., whilst carbohydrates increase the giving off of CO_2 more than the taking in of oxygen. In rats with a meal rich in carbohydrates, CO_2 rose to 97 per cent., the oxygen to 35 per cent. above the values obtained in the fasting condition.

The Effect of Absolute Rest and Sleep on Metabolism.

The minimal amount of metabolism as a rule is smaller. During sleep the consumption of oxygen sinks from one to six per cent.; the amount of carbon dioxide during sleep is decreased 6.5 per cent. In absolute rest of the body the intake of oxygen is decreased and the outtake of carbon dioxide diminished.

Effect of Muscular Work on Metabolism.

The respiratory exchange is increased in all kinds of work. The quantity of air breathed is also increased. Severe work causes the gaseous exchange to increase during hard work about five to seven times its amount during rest.

When work is ended the gaseous exchange returns to normal within four to nine minutes after medium work. Massage has no marked effect upon metabolism, producing, however, a small increase. The increase of utilization of oxygen in muscular work is in part due to increased activity of the muscles of the cardiac and respiratory apparatus. In muscular work the proteid is not used, for urea is not increased, but the carbohydrates and fats are made use of. The fats are somewhat behind the carbohydrates in the formation of energy. Atwater's results prove that fats and carbohydrates may be exchanged for one another in a mixed diet and keep up the level of energy. The question then arises, Does the muscle use the carbohydrates and fats directly, or are they changed into glucose first before being utilized? It is not decided whether glycogen and the fats are directly used or that they must first be changed into glucose.

When the proteids are used in muscular work they probably have in the liver their nitrogen part changed into urea, and the carbon moiety is stored as glycogen or fat and directly oxidized in muscle work. Fifty-eight per cent. by weight of the meat proteid metabolized according to Lusk, can be converted into sugar in the body. About fifty per cent. of the proteid taken becomes, by the exogenous metabolism of the liver, converted into urea. The remainder goes to repair the tissue or organized proteid of the body. The endogenous metabolism of the organized proteid of the body is indicated not by the urea, but by the creatinin and to a lesser degree by the uric acid. The question now arises, Why not give carbohydrates and fats instead of proteids? as the nitrogen moiety is removed by the liver and excreted by the kidney. It is probable that in the splitting of proteid there are many different kinds of amino-acids produced. These building stones must be of various varieties to fit in the building up of the tissues or organized tissue proteid.

Atwater and Benedict have shown that the total metabolism on an alcohol diet was no greater than on a diet without alcohol; in both cases the same amount of work having been performed. In these experiments 72 grammes of alcohol were taken in the course of the day in place of an iso-caloric amount of fat. Here alcohol indirectly serves as a source of energy for muscular work, but only by taking the place of fats and carbohydrates as a generator of heat. Alcohol in this amount does not lower the energy produced by the other foodstuffs.

Frenzel found that sugar increased the activity of muscle when exhausted, but he also found that protein in iso-dynamic quantities was much more effective, and whilst the saccharose lost its effect at the end of the third hour, the effect of proteid continued until the seventh hour.

Action of Various Agencies upon Metabolism.

Mental activity has no direct effect upon metabolism. The glands especially are, next to the muscles, generators of heat. Sunshine acts upon metabolism by increasing the activity of the nervous system and thus the movements of the muscular system, which produces more energy. Sunshine has no direct action on metabolism. Cold increases the generation of heat, the consumption of oxygen and the exhalation of carbon dioxide. With a rise of external temperature the increase in metabolism in warm-blooded animals is less than when the temperature falls. Cold baths or douches may increase the oxygen and carbon dioxide exchange from 50 to 200 per cent.; hot baths increase them from 50 to 100 per cent. At the seashore gaseous exchanges were increased in two individuals, but not in a third one.

Alterations of pressure in air chambers, whether a decrease of 450 millimeters or an increase of 1,500 millimeters, do not affect the consumption of oxygen in the dog or man. This is true in rest and in work. In high altitudes the respiratory gaseous exchange is primarily increased 10 to 20 per cent. compared with persons living on the low lands and not used to climbing mountains. This result is neither due to a diminution of pressure nor only due to increase of work by the muscles of respiration. It is a result of some climatic influence to which the body must adapt itself.

Effect of Age and Size.—In the infant and the child the taking in of O and taking out of CO_2 is greater than in the adult, due to the relation between skin surface and mass, for the larger the animal is the smaller the ratio between the surface and its mass, for surface increases as its square and weight as its cube. In old people the respiratory exchange is smaller than in the adult, due to quietude and loss of tone in the muscles.

The smaller animal has a greater exchange of O and CO_2 than a larger animal.

Sonden and Tigerstedt show that there is a greater combustion due to the age of the child, the younger the child the greater the excess of combustion. The male child excretes more CO_2 than the female of same age and weight, due to the greater activity and tonus of the muscles.

Luxus Consumption.

In Liebig's old theory, the fats and carbohydrates were supposed to generate heat, whilst the proteids were muscle-builders, and the life phenomena were supposed to be due to chemical changes in the proteid. When it was found out that proteids in part also generated heat, it was looked upon as a wasteful use of good material, and was denominated a luxus consumption.

The luxus consumption theory of Voit is that the excess of proteids in the blood and lymph is oxidized in those fluids. Hence we see there can be a dividing line made between the circulating proteid of the blood and the lymph and the organ proteid of the cells.

Unorganized and organized proteid are better terms than circulating and tissue proteid of Voit. The tissue proteid or stable proteid is hard to disintegrate.

It is now believed, according to Abderhalden, that the amido acids are the circulating or unorganized proteid of Voit.

INTERMEDIATE METABOLISM.

According to Pasteur, all oxidations are accomplished by intracellular ferments of the cells of the tissues, which are denominated oxidases. The act of autolysis proves that intracellular ferments exist.

The act of autolysis or digestion outside the body under antiseptic precautions produces with the proteids all the products found when digestion takes place in the intestine. Here the intracellular enzymes are the active agents.

All the tissues of the body have a large number of enzymes capable of producing a great variety of metabolic products. The intracellular ferments are the controlling factor by which the needs of the body are supplied with metabolic products.

Every species of animal has its own specific proteid as the precipitin test shows. The caseins of different kinds of milk when injected into the circulation also produce specific precipitins by means of which these caseins can be differentiated from one another. No matter what kind of food of a proteid nature is taken into the intestine, the serum-albumin and serum-globulin is constantly of the same composition. It is inferred that the amino-acids and polypeptids of the food-proteid are synthetically built up into proteid suited to that particular kind of animal. The serum-proteids are independent in composition of the kind of proteid-food for a horse fed with gliadin, five times richer in glutaminic acid than serum-proteid, yet its serum-proteid had the normal amount of glutaminic acid even when the animal had been bled profusely and must generate a large amount of serum-proteid. Hence the intestinal wall and the ferments have the important function to always furnish the same proteids to the tissues. It is evident that not all proteids can have the same food value to the animal body and their value can not be determined by their content of nitrogen. A food-proteid that yields very little serum-proteid when its amido-acids are resynthesized in the intestinal wall can not replace in equivalent amounts a food-proteid that yields amido-acids in more nearly the same proportion in which they are found in serum-proteids. Hence, if a certain food-proteid contains very much less of an amino-acid than the serum-proteid does, then only a correspondingly small amount of its other amino-acids can be used in the building up of tissues. It is probable that the tissue cells have some selective power, as the proteids in these cells of the tissues have a certain proportion of the various amido-acids different from those of the serum-proteids. The portal circulation carries to the liver the specific serum-proteids with polypeptids, amido-acids and ammonia. The blood going to the liver also conveys indol, skatol, phenol and cresol, products of microbian digestion which go to the liver to form the conjugated sulphates. The liver also forms glycuronates, as indoxyl, skatol and phenol glycuronates, which, with the ethereal sulphates, are carried to the kidney and excreted.

Leathes states that the two main products of proteid metabolism, urea and carbonic acid, are to a great extent produced independently of each other, and the reactions which result in the discharge of nitrogen are not those in which energy is set free, work done and carbonic acid produced. This being so, it is plain that proteid metabolism, in so far as it is concerned with evolution of energy in its exothermic stages, may be almost entirely nonnitrogenous metabolism.

We can not take the excretion of urea as a measure of proteid metabolism, because a large part of it is formed from nitrogen that has never penetrated the body beyond the liver.

The body is able to interchange the proteids of the tissues which are distinctly different; hence it can build specific proteid out of the neutral proteid of the blood. In the fasting salmon Miescher found that the proteid of vanishing muscles was changed into the proteid of the testicles which grew at that period. In starvation the heart-muscle does not waste, but acquires its proteid from the other proteids of the body.

A cleavage by hydrolysis must precede every transformation of proteid inside the body.

The amino-acids and polypeptids enter the general circulation. Leathes and Howell have found amido-acids in the blood. When the amido-acids arrive at the tissue cells they undergo two changes: they may be used as keystones in building up the tissue proteid, or they may be broken up by the intracellular ferments, forming ammonia, which is excreted as urea. When the proteids of the blood are in contact with the cells the intracellular ferments break them up into polypeptids and build them into their own peculiar tissue. When the polypeptids are injected into the circulation they do not appear in the urine as polypeptids or in the shape of amido-acids, which formed them, but probably as urea. In the breaking down of proteids by the intracellular ferments we have the old amino-acids replaced by the new building stones, the new amino-acids. These old amino-acids are broken up into ammonia and changed into urea. In certain families the amido-acids are not acted upon by the intracellular ferments; then you have cystinuria and alkaptonuria. In alkaptonuria the patient excretes homogentisinic acid, which is derived from the amino-acids, tyrosin and phenylalanin. One of the amino-acids, glycocoll, on its way to be excreted, meets benzoic acid and forms hippuric acid. Glycocoll may also unite with poisons in the blood in a like manner, taking away their toxic properties and excreting them. Alanin and glycocoll, two amido-acids, when given increase the excretion of sugar in pancreatic diabetes. In the metabolism of the body the amido-acids occupy the front rank.

Specific Dynamic Action of Proteids.

Rubner believes that proteids stimulate the metabolism of the body to a greater degree than carbohydrates or fats. Rubner found that after taking meat in excess of starving metabolism, the specific dynamic action caused a heat increase of 32.28 per cent. After ingestion of a smaller quantity the specific dynamic action was only 29.60 per cent. The average of these or 30.94 per cent. represents the specific dynamic action of proteid or the increased heat production after the ingestion of meat containing 100 per cent. of the energy-requirement. When proteids break up in metabolism sugar is produced in considerable quantity, which gives heat but not energy to the cells. Proteids in the body are most readily metabolized. Fats are the most difficult to burn. Outside the body fats are more easily burnt than either carbohydrates or proteids.

Proteid Metabolism.

Pflüger's dog fed upon flesh a long time and working hard, excreted somewhat more nitrogen than ingested, so that some proteid is used in work. But when fats and carbohydrates are abundant they are the main source of energy in muscular work. One hundred to one hundred and twenty grams of proteid should be allowed daily per adult.

Man can live only when the chemical elements are arranged in a certain manner with others in the form of foods, for the proportion of carbon to nitrogen in foods is not that required in a diet. If sufficient proteid was used to supply carbon, the diet would contain four times more nitrogen than the body needs. If he received enough proteid to furnish the nitrogen required, then he would be deficient in carbon. Hence it is plain that man's diet should be made up of proteids, fats, carbohydrates, water and salts.

Each gram of nitrogen corresponds to 6.25 grams of proteid; and since meat contains on an average 34 per cent. of nitrogen, each gram of the latter will represent 30 grams of muscle.

Living proteid is not destroyed either in metabolism of proteid or in that of the nonnitrogenous materials, but is comparatively stable.

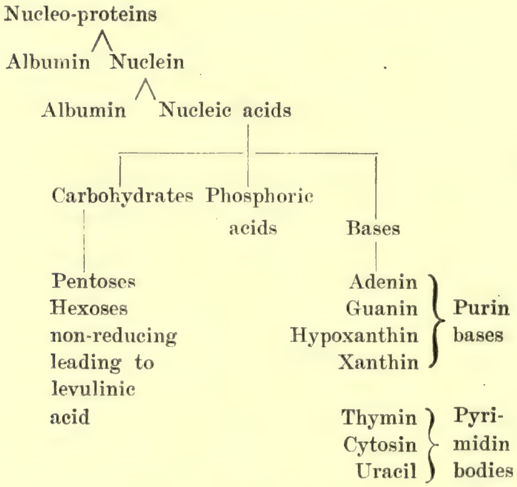
Folin holds that there are two kinds of proteid metabolism, one constant, the other variable. The variable form, exogenous metabolism, has urea as its chief product. Urea represents the products of foods which have undergone hydrolysis by trypsin and erepsin, the nitrogen part going to liver to form urea, whilst the carbonaceous residue is converted into carbohydrate or oxidized. The constant form, endogenous or tissue metabolism is represented chiefly by creatinin and by uric acid. Creatinin is a constant quantity, no matter how much variation in the food-proteid, provided meat is not used, as it contains creatinin. Hence creatinin is an index of tissue proteid metabolism.

Storage of Proteids.—The storage of proteids is denied by some physiologists. It certainly is not so readily stored as fats and carbohydrates.

The body can only store proteid when the substances ingested are reinforced by substantial additions of carbohydrates and fats.

In order to obtain the greatest total deposit of proteid in the body it is best to give a relatively large quantity of fat in comparison to the quantity of meat. The carbohydrates have the same relation to the storing of proteid as the fat, and in a much greater degree. All this proves that in recovering from a wasting fever you must use, with proteid, carbohydrates and fats.

Nucleo-proteids.—When the nucleo-proteids enter the intestine the nuclein undergoes hydrolysis by the proteolytic agents, and the now soluble nuclein enters the blood. The intracellular ferment, nuclease, in the tissues breaks up the nuclein in the manner shown in the following table from Von Noorden.


Nucleo-proteins
Albumin
Nuclein
Albumin
Nucleic acids
Carbohydrates
Phosphoric acids
Bases
Pentoses
Hexoses
non-reducing leading to levulinic acid
Adenin
Guanin
Hypoxanthin
Xanthin
Purin bases
Thymin
Cytosin
Uracil
Pyrimidin bodies

The relations between the purin bodies are shown in the following summary:—

Purin		$= C_5H_4N_4$
Amino-purin	Adenin	$= C_5H_5N_5 =$ 6-amino-purin
	Guanin	$= C_5H_5N_5O =$ 2-amino — 6-oxypurin
Oxy-purin	Hypoxanthin	$= C_5H_4N_4O =$ 6-oxypurin
	Xanthin	$= C_5H_4N_4O_2 =$ 2.6-oxypurin
	Uric acid	$= C_5H_4N_4O_3 =$ 2.6.8-trioxypurin

The purin base guanin by guanase is converted into xanthin, and the base adenin by adenase into hypoxanthin. The xanthin oxidase by oxidation converts hypoxanthin and xanthin into uric acid. Hypoxanthin by the mouth in man increases the excretion of uric acid. The purin bases are present in beer and porter, coming from the nuclein of the yeast. Alcohol has no striking action upon the excretion of uric acid. Salicylic acid has a decided increased action on the output of uric acid.

The different tissues contain a uricolytic ferment which breaks up uric acid into urea and other bodies. The liver seems to be the principal seat for the destruction of uric acid. In diabetes there is an inability of the tissues to destroy sugar; in gout the symptoms are dependent upon the deposit of acid urate of sodium in certain localities.

Metabolism of Carbohydrates.

When carbohydrates enter the tissues they may (1) undergo combustion, (2) may be stored up as glycogen or fat, or (3) being only partly consumed they may be excreted in the urine.

Nencki has shown that 10 per cent. glucose when mixed with 20 per cent. of caustic alkali at the temperature of the body, at the end of twenty-four hours contains only traces of sugar, but lactic acid amounting to 50 per cent. of the sugar taken. Bacteria change grape sugar into 80 per cent. of lactic acid. Buchner believes that the first stage in the alcoholic fermentation of sugar is due to zymase changing sugar into lactic acid, and lactacidase, a second ferment of the yeast cell, converting the lactic acid into alcohol.

Asher and Jackson removed all the abdominal viscera in a dog and they found that the lactic acid in the blood was increased. Minkowski extirpated the liver in geese, and here lactic acid and ammonia replaced the uric acid in the urine.

Proteids in breaking up into the amino-acids form one, alanine, which may be a small source of lactic acid. We know that in muscle activity sarco-lactic acid is formed.

Alanine when given to rabbits, causes glycogen to be deposited in the liver and the excretion of lactic acid by the kidneys. The glycerine in the body can produce sugar. The nucleo-proteids also have a carbohydrate or pentose, and the gluco-proteids contain glucosamine, but how far they are concerned in metabolism is still a matter of obscurity.

In certain families a pentosuria exists, a carbohydrate of the five carbon series, a pentose is excreted. The sugar excreted is the optically inactive racemic, arabinose. It arises within the organism itself. This diabetes needs no dieting.

Sugar may become oxidized in the body without previous splitting, so that the first product to appear is glycuronic acid. Cohnheim's theory is that a destruction of sugar by muscle extract combined with the pancreatic activator occurs.

The ingested carbohydrates are all destroyed before the body fat and the fat in the food.

Muscles consume, besides the carbohydrates and fats, also the proteids. In extreme cases where no carbohydrates or fats are present the proteids are used.

The sparing of proteid by carbohydrates is greater than by fats, an important dietetic fact.

Kossa has shown that the subcutaneous injection of sugar up to saturation in fowls, and to a lesser extent in dogs, produced profound changes, followed by death of the animals. The metabolism of albumin rose 50 per cent. and the excretion of urea rose from 12 to 17 grams. The phosphoric acid rose at the same time in direct relation to the urea.

Storage of Carbohydrates in the Body.—Glycogen was discovered by Bernard to be stored in the liver and muscles. Eleven grams of glycogen per kilogram exists in the dog, according to Pflüger.

Fasting removes glycogen, but not all of it. Severe muscular work removes glycogen from the body, both from the liver and the muscles.

The carbohydrates are the chief source of glycogen. Proteids are also a source of glycogen. According to Pflüger, glycogen may be made by fat.

They pass into the liver by the portal circulation as dextrose and are partly stored up in the liver-cell as glycogen, to be given off as sugar in the periods between digestion, to be used up when a sudden demand is made by the starving or working body. The dextrose is used up by the muscle- and gland-cells, being oxidized, the carbon going off as carbon dioxide. As to amount of carbohydrates, only 500 grammes can be consumed without digestive disturbance.

The carbohydrates are found in small proportion in flesh foods, as glycogen, and in milk in the form of lactose. By far the greater proportions of carbohydrates are obtained from the vegetable kingdom. In vegetable foods they occur as starches and sugars.

An animal that is fed upon carbohydrates exclusively dies of starvation on account of want of proteid. The saving of proteid increases proportionately with the quantity of carbohydrates ingested. This is an important fact, since the digestive juices are capable of digesting them in large quantities.

The fatigue of muscle is slowed by the use of sugar. For four days Dr. F. S. Lee gave animals phloridzin, which sweeps the greater part of the carbohydrate material, or glycogen, out of the muscles. Then he irritated the tibialis anticus, and, while it gave 1,000 contractions per minute on electrical stimulation normally, after the removal of glycogen by the phloridzin the contractions were only from 200 to 400 per minute. These experiments proved that carbohydrates assisted the muscle in its contraction. He made another series of experiments upon the muscles which had their glycogen removed by phloridzin, and then gave 50 grams of dextrose. Then electrical irritations were used on the muscle, which gave 560 contractions per minute. Here the glucose restored the muscle.

Fats.

The quantity of fat in healthy persons may vary greatly: from 2.5 to 23 per cent. Fats are encountered in two forms in the organism: (*a*) as an emulsion in the nutritive fluids; (*b*) in drops in small particular cells, or in the interior of tissue cells. While in the state of emulsion the fats are in circulation; in the second state they are at rest. The combustion of fats produces water and CO_2.

The fats can be stored by the feeding of fat. When Munk fed a dog, starved for thirty-three days, with meat and some rape seed oil daily for seventeen days, he found at the end of the time a large quantity of fat, which showed a storing of fat from the oil. In this fat was found erucic acid, which belongs to the rape seed oil and not to normal fat. Fats can be stored from soaps and fatty acids.

In organs continuously working we find fat, especially in the heart and kidneys. There is more in the kidney than in the heart.

Fat is also produced from the carbohydrates. Fats are used up during abstinence, during insufficient diet, or during sickness. The energy of fat is transformed into heat and into mechanical or chemical work. Fat is a steady source of energy in work. Hence, a man who works has need of more fat than one who pursues a sedentary life.

The liver becomes loaded with fat from poisoning by phosphorus. Here the fat is imported from other storage places in the body, especially from the subcutaneous fat of the abdomen.

Proteid decomposition is primarily in relation with the amount of proteid ingested. As the amount of proteid given increases, the amount of fat burned decreases. The addition of a considerable amount of fat to a proteid diet neither increases the metabolism of fats nor the total metabolism.

The fats are savers of proteids, as they are used before the proteids are attacked in metabolism.

Sugar and starch are converted into hexoses and these are transformed and built up into glycogen. Fats are broken up into fatty acids and glycerine, not changed, but used as fat.

Zuntz finds that fat can be used for muscular work with as much economy as either proteids or carbohydrates. In fact, with fat, slightly less oxygen and energy was required to do work on fat diet than with the others.

The following table shows the results when resting and working on a diet principally of fat or of a carbohydrate or of a proteid (Leathes) :—

Diet principally	Resting		Working			Per M. kg of work	
	c. c. oxygen used per min.	Resp. quotient	c. c. oxygen used per min.	Resp. quotient	M. kg of work done	c. c. oxygen used	Cal.
Fat	319	0.73	1029	0.72	354	2.01	9.39
Carbohydrates	277	0.9	1029	0.9	346	2.17	10.41
Proteid	306	0.8	1127	0.8	345	2.38	11.35

During fasting the fats from their storage places return to the blood, to supply the needed fat. The liver first transfers the fat in starvation from the subcutaneous tissue and the abdomen. This transfer of fat to the liver only ensues if glycogen has vanished, and it can be prevented if the animal is fed with substances which rapidly form glycogen. This transfer of fat to the liver is a reserve which meets any emergency call upon the cells of the body for fat, as in violent exercise. The vascular liver can give fat to the blood much more rapidly than the cells of adipose tissue in the subcutaneous tissue. Hence the liver supplies glycogen and fat for the sudden needs of the body.

Hanriot has discovered a lipase in the blood which breaks up the fat in the blood into fatty acid and glycerine and makes them soluble in water, so that they can pass through the wall of the capillary to the tissue. A lipase in the tissues also breaks up the fat, so it can return to the blood.

According to Leathes, "the fatty acids undergo oxidation step by step, each time at the B. carbon atom; that an unsaturated linkage is the first move towards this oxidation, and probably the formation of a saturated oxyacid the second. The first of these preparatory changes takes place either in the organs where the oxidation is carried out or before it reaches them, but after it leaves the storage places possibly in the liver."

Pflüger believes that the sugar produced in the body which cannot be accounted for by the carbohydrates must be derived from the fats. In his dogs who had the greater part of the pancreas removed and the connection of the remainder with the intestine severed, there ensued a glycosuria. He then fed them with raw ox-pancreas, which increased the absorption of fats and proteids, and there resulted an intense glycosuria. He fed them four months on casein and boiled cod, which in the winter months contains no glycogen and only traces of fat. By calculations he deduced the conclusion that the sugar was derived from the fat, and the seat of this transformation was the liver. Pflüger does not believe that fats can come from proteids.

In fatty conditions of the organs, as the liver and heart, the fat has been transported from the storage places in the subcutaneous tissues, especially in that of the abdomen, to the organ affected. The fat is not due to an alteration of the tissues of the organ.

Acetone Bodies.

Betaoxybutyric acid by oxidation gives rise to acetic acid and this by losing carbonic acid produces acetone. Acetone is the only body appearing in normal urine. Acetonuria is constantly produced in healthy people by restricting the carbohydrates, but it disappears as soon as the carbohydrates are restored. In a healthy man fed on butter, oil and a little wine for five days there was found in the urine diacetic acid, B.-oxybutyric acid and acetone in amounts as in severe diabetes. Of all the fatty acids, butyric acid of butter is the most powerful to cause acetonuria. Acetone is largely formed in the muscles and liver, and to a small extent in the other tissues of the body. It is especially in diabetes that acetic and oxybutyric acid appear.

Inorganic Substances.

Like water, the inorganic substances are absorbed in excess. more than is necessary to a normal minimum.

An animal can abstain from all food and live longer than an animal deprived of salts.

The mineral salts are cast off in smaller amounts when no salts are ingested, but they are never entirely absent. With organic food materials the amount of salts excreted is minimal.

Oxygen.—We take in about 700 grams of oxygen, which is necessary to oxidize the foods.

Water.—Bread contains 34 per cent. of water; meat 55 to 75 per cent. of water.

Among the inorganic compounds, the most important, without exception, is water. It is even more important than proteid and fat, since it forms about three-fifths of the weight of the body.

Water has an important function within the organism. When proteid is insufficient, water accumulates in the tissues. Among the poorer classes, whose nourishment is insufficient, infectious diseases flourish, since their nutritive liquids are excellent media for the cultivation of micro-organisms.

Excess of water causes an augmentation of urea; hence the success of mineral waters in Bright's disease. This increase of urea is due to the abundant washing out of the retarded metabolic acts through the kidneys.

Atwater and Benedict found in repose the amount of water taken in on an average to be 2,290 cubic centimeters, on working days 3,700 cubic centimeters. In addition the body has water manufactured in it by the oxidation of hydrogen in the food. The oxidation water amounts to about 360 grams in a mixed diet, representing 3,000 calories. Water is excreted only in relatively small amount by the fæces, 60 to 120 grams daily. Atwater and Benedict state that an average of 931 grams of water is given off by the skin and lungs during a day, of which 531 grams come from the skin and 400 grams from the lungs. Work greatly increases the evaporation from the skin. The evaporation of water from the body is least in temperate climates, greater at low temperature and much increased by high temperature. The body loses less water in damp than in dry air. A strong sunlight increases the evaporation of water.

Increase of adipose tissue diminishes the water lost at low temperature, but greatly increases it at a high temperature. The ingestion of water in repose increases the amount of urine, but leaves the evaporation unchanged. Alcohol when taken in considerable quantities increases the sweat excretion, due to the vasodilation in the skin. The evaporation of a liter of water takes away from the body 580 calories. Atwater and Benedict set down the heat lost by evaporation during repose at 24.5 of the total. In a man with congenital defect of the sweat glands his temperature rapidly rose to 40-41 degrees C. when he did heavy manual labor or after he sat for some time in the rays of a summer sun.

When the body is in nitrogenous equilibrium and more water is drunk, then the nitrogen in the urine increases if there is diuresis, because the tissues are more thoroughly washed out. In thirst the consumption of oxygen is not increased; hence the diminution of water does not have any effect on fat in obesity. Thirst increases the excretion of nitrogen.

Mineral Substances.

There is neither any liquid nor any tissue which does not produce an ash upon calcination. The inorganic salts are either in solution or combined with organic substances, notably proteid. The combination of the various needful salts with protoplasm, the substratum of life, is of the highest importance.

Förster, of Strassburg, is of the opinion that certain combustible compounds of foodstuffs and the body tissues, with regard to which there is as yet little exact knowledge, play an important part in nutrition. Pigeons could be kept alive when fed exclusively on wheat, but if the wheat were extracted with dilute acids the pigeons died in from three to four weeks. If the substances thus extracted were added to the treated wheat, death still occurred. This proved that the elementary ash must be combined with the cell in order to be utilized.[1]

The nature and quantity of mineral substances demanded by the growth of the child is clearly indicated in the composition of milk. The human body loses about 25 grammes of mineral substances a day, of which one-half is sodium chloride, the other half potassium sulphate and phosphate; also sodium phosphate and sulphate, lime, magnesia and a small quantity of iron. The mineral salts also have a function. The salts of soda favor a solution of the proteid substances in the blood. Iron is indispensable; lime is necessary for the coagulation of the blood, milk and myosin. The ions of lime and potash and soda combined in Ringer's solution maintain the functional activity of the heart and contractile tissues. The salts of lime modify the irritability of the central nervous system. The iodine in the thyroid gland is intimately concerned in nutrition.

Potassium and Sodium.—Potassium is found in all the vegetable and animal cells. Sodium is found especially in the blood plasma and in the liquids of the organism. These two basic bodies are indispensable to life. Without mineral salts in the food the proteids in decomposition give up sulphur, which is oxidized in great part and becomes sulphuric acid. The cells are injured by it and its presence in the blood is not compatible with life. There is caused a train of symptoms indicating a disturbance of the central nervous apparatus and the digestive system.

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[1] British Med. Jour., p. 1077, 1907.

Sodium Salts.—Chlorine is not united with proteid, but exists always in an inorganic form. Sodium chloride in moderate doses reduces nitrogenous metabolism. When sodium chloride is withdrawn from the diet of man his weight decreases, for water is lost with sodium chloride. In starvation small doses of sodium chloride increase the water in the tissues and render the animal more capable of resistance. When the body is deprived of salt the blood becomes somewhat concentrated. Osmotic pressure explains in part the close relation between the quantity of water and that of sodium chloride.

The uniformity of osmotic pressure is in part due to the constant proportion of sodium chloride present, which exerts 50 per cent. of the osmotic pressure.

In human serum Hamburger has calculated 25 per cent. as non-electrolytes, that is, organic substances; whilst 75 per cent. consists of electrolytes—that is sodium chloride, 50 per cent. and 25 per cent. of other salts, as sodium carbonate, etc.

Salt is necessary to the constitution of the blood, lymph, the formation of bile and gastric juice. It also keeps in solution many nitrogenous compounds which are eliminated by the urine. The vegetarian should eat more salt, as the salts of potash in the vegetables exceed by three times the salts of soda.

Now, the bases in the blood which neutralize are the sodium carbonate and sodium phosphate; and it has been estimated that the amount of this alkaline reacting alkali, or native alkali, in the entire body is equivalent to 60 grams of sodium hydroxide ($NaOH$). This amount of alkali is so small that it would be quickly exhausted by a persistent acid intoxication, with a persistent formation of only small amounts of acid. Certain diabetic patients pass daily, for long periods, a large amount of acids which are excreted by the urine in combination with bases, it being understood that the urine does not contain free acid. As the native alkali of the body is not sufficient to neutralize so much acid, it is necessary that there should be another and more enduring source of alkali than the native. For this ammonia is generated by proteid metabolism of the cells, and especially of meat. The acids in diabetes are aceto-acetic and the oxybutyric, which can be detected in the urine. Acetone is also present in the urine of severely diseased diabetics.

Phosphorus.—Phosphorus is found in all the cells in the shape of lecithin, a nucleo-proteid.

The pathway of elimination of phosphorus is mainly in the fæces. Phosphorus can be supplied to the body both in inorganic and organic combinations, as both compounds can be absorbed from the intestines. The average daily quantity of phosphorus needed is about two grams.

If the supply of phosphoric acid is not sufficient the body is not able to limit the excretion of phosphoric acid to the same extent as is possible in the case of chlorine under similar conditions. In fasting the body gives off phosphoric acid until the end. The muscles of the body contain nitrogen and phosphoric acid in certain proportions. A certain relation exists between the progress of excretion of nitrogen and of phosphorus.

In man's muscles the relation between nitrogen and phosphoric acid is about as follows:—

$$\frac{N}{P_2O_5} \quad \frac{100}{13.7} = 7.3; \text{ or, } \frac{N}{P} = 16.7.$$

Calcium and Magnesium.—These bodies are excreted and absorbed by the intestines as inorganic compounds. In the fæces there is an average of 0.16 grams of calcium and 0.06 grams of magnesium per day. Tigerstedt calculates that a daily supply of 0.3-0.7 grams of calcium and of about 0.4 grams of magnesium is necessary.

Lime is abundant in cartilage and bone. Magnesium predominates in the blood-corpuscles. In the infant much lime furnished by the milk is used in the development of the skeleton.

Lime occurs in large amount in milk. The only other food which has the same amount as milk is the *yelk of egg*. This latter should be given to children when milk is not at hand or not readily digested. Calcium is excreted chiefly with the succus entericus.

Rickets follows when there is not sufficient calcium in the food, and also in cases where calcium is sufficient but the cells of the bone and tissue cannot assimilate the lime.

The alkaline earths, if in too great quantity, may precipitate and form hepatic calculi.

Chlorine, Fluorine and Iodine.—Chlorine is found in all the tissues, united with potassium, sodium and calcium. Hydrochloric acid is an element in the gastric juice. Fluorine exists in bone and the yelk of eggs. Iodine exists in the thyroid gland as iodothyrin,

Sulphur.—This is furnished especially by the vegetable and animal proteids. A certain proportion exists between the total nitrogen and the total amount of sulphur excreted, as proteid metabolism furnishes both. For one gram of sulphur, fourteen to sixteen grams of nitrogen are excreted.

Iron.—Such compounds of iron as are contained in nuclein found in the yelk of egg have been termed by Bunge, *hæmatogens.* In the chick the developing red corpuscles obtain their iron from it. Iron is absorbed through the duodenum and excreted mainly through the mucous membrane of the colon. Inorganic and organic combinations of iron are absorbed. Iron is deposited in lymph-ganglia, spleen and liver.

The Aim of Alimentation.

Alimentation has for its end (1) to furnish materials for catabolism, and (2) to furnish suitable products for anabolism. That is, to replace and rejuvenate the organized substances which are destroyed in the former process.

To know what are the foods which the body needs, it becomes necessary to study the substances which undergo anabolism and catabolism. It is these substances which must enter into our daily nourishment. These two processes ensue in all of the substances, without any exception, which compose the organism. Hence, all the principles of which the economy is composed are indispensable in food: water, proteids, fat, carbohydrates and salts.

Foods.—Each one of these principles taken in an isolated manner is not a complete food, since it is not able to replace its neighbor. Thus, water is as necessary a food as is proteid, but yet water is not a complete food.

A *food* is any product which is capable of being transformed into a proximate principle of the organism, or capable of at least diminishing or preventing the destruction of this principle. Hence, a *complete food* is the sum of the food-products capable of preserving or augmenting the sum of the proximate principles of which the organism is composed.

The fundamental principles which enter into the chemical composition of the human body—water, proteids, fats, carbohydrates and salts—are in themselves composed of simple elements: O, H, C, S, N, P, Cl, K, Na, Mg, Fe, silicon and fluorin.

Will these simple elements, upon ingestion, become converted into complex principles and so constitute foods?

They will in the case of the plant, for it is able to form a complex frame by the aid of simple elements. The plant is a *synthetic* laboratory of *chemistry.* But this is not true of the animal organization. The latter is incapable of anabolism and life except by the aid of complex food-combinations such as have been formed by the plant. Contrary to the plant, the animal is a laboratory of *analytical chemistry.* The animal can only form by synthesis combinations of a low degree, as water, benzoic acid and ammonia, which cannot be built up in the animal. But the plant can take H, O, CO_2 and N, and from them make complex and elevated combinations.

Balance of Nutritive Exchange.

To ascertain the balance of nutritive exchange, a comparison is made between the ingesta and egesta: between the gains and losses. The ingesta consist of food and oxygen; the egesta of various excreta and of the carbon dioxide and water lost by the lungs and skin. When the ingesta equal the egesta and the organism neither gains nor loses weight, there is a *complete nutritive equilibrium.*

A balance of *water* is made by giving, upon the one side, the quantity of water ingested by the foods and drinks; upon the other, the quantity of water eliminated by the stools, urine, skin and lungs. As the hydrogen contained in the food is oxidized and transformed into water, it is evident that in a state of equilibrium the quantity of water eliminated will be much greater than that ingested. By comparing the water ingested with the water egested, it is found how much oxygen serves to burn the hydrogen.

Definite enough information is obtained regarding the balance of metabolism if the *nitrogen* and carbon only are determined in the ingesta and egesta.

The balance of *proteid* is made by a comparison of the nitrogen ingested with that egested, for the amount of nitrogen permits us to know the quantity of proteid, since 100 parts of proteid contain 16 parts of nitrogen. The nitrogen eliminated is found in the urine.

Nearly all of the proteid that is destroyed is found in the form of urea, uric acid, creatinin and hippuric acid in the urine. There is also found in the stools proteid which has not been digested nor absorbed along the digestive tract. A part of the nitrogen is eliminated by the desquamation of hairs, nails and epidermis. But it usually suffices to determine the amount of nitrogen in the stools and urine.

If, in making up the balance, it be found that the ingesta have more than equaled the egesta, it is concluded that there has been an *anabolism* of nitrogen. On the other hand, should the egesta contain more nitrogen than the ingesta, then there has been a *catabolism* of proteid. Should the income and the output be equal, it is concluded that there is a state of nitrogenous equilibrium.

The *carbon* contained in the foods and organized tissues, and which is destroyed by catabolic phenomena, is eliminated by the skin and lungs under the form of CO_2, by the urine and stools under the form of carbonated organic compounds. From the comparisons of the ingesta and egesta it is ascertained whether there is carbon anabolism, catabolism or equilibrium.

Proteids, fats and carbohydrates all contain carbon; so that if there be a gain or loss of carbon it may be from the proteids, fats and carbohydrates. To arrive at some solution, it becomes necessary to calculate the quantity of nitrogen eliminated. Every hundred parts of proteid contain 53.6 parts of carbon and 16 parts of nitrogen. If it be known how much proteid has been destroyed nothing is easier than to calculate the quantity of carbon which belongs to it. The remaining carbon that is eliminated must belong to the fats and carbohydrates.

All of the carbohydrates ingested, except those stored up as glycogen, are burned up in the metabolism of the tissues and their carbon found in the excreta. Hence, by calculating the quantity of carbon which is found in the ingested carbohydrates, one finds what quantity of carbon eliminated belongs to the decomposition of the carbohydrates. If there be an *excess* of carbon it must come from the fats, since the latter contain, as a mean, 76.5 per cent. of carbon. By multiplying the surplus of carbon by 1.3, there is found the quantity of fat which is gained or lost.

By nitrogen equilibrium we mean the condition of man when the nitrogen of the egesta is equal to the nitrogen of the ingesta, and this is the normal state of man when properly nourished. If the nitrogen of the ingesta is increased, or even in excess, it is not deposited in the tissues, but after a short time is excreted, the man eating more and excreting more.

By carbon equilibrium is meant a condition in man where the total carbon of the excreta is equal to the carbon taken in in the ingesta.

Nitrogen Equilibrium.

The quantity of proteid food to preserve nitrogenous equilibrium varies with the state of the body; a thin man needs less than a muscular and well-nourished one.

A body can be maintained by proteid food alone in a state of nitrogen equilibrium. If, however, you add nonproteid foods, it is seen that the amount of proteid necessary to nitrogen equilibrium can be lessened; hence the nonproteid foods are sparers of proteid. Hence you decrease the proteid food and increase the nonproteid food, yet the body does not lose more proteid than before, and nitrogen equilibrium continues as before. The proteids develop energy by oxidation, especially that form manifested in the shape of heat, and also reconstitute the protoplasm. But the nonproteid foods can also develop heat and work, and thus can substitute for the proteid foods in part.

Hence an animal may be kept in nitrogen equilibrium on a much smaller amount of proteids, provided fats or carbohydrates are eaten.

When a fat animal takes proteid in large amounts, then the destruction of fat is increased; and if there is hardly any fat in the food, the fat stored up in the animal will lessen.

Each increase of proteid ingested produces a rise in proteid metabolism; hence a nitrogen equilibrium can be obtained on the many different amounts of proteid. The body is unable to store any large quantity of proteid.

If a person living on a diet which will keep up equilibrium with the proteids undergoing complete metabolism, then increasing the nonnitrogenous food in the diet will cause some of the protein to remain stored in the body. If with sufficient diet a large quantity of carbohydrates be dispensed with in the diet the protein destruction is increased; the body then seizes upon its own protein and the stored fats and carbohydrates.

Other conditions being equal, the amount of nitrogen eliminated depends upon the richness of fat in the tissues; a fat animal eliminates less nitrogen than a lean one. In case of a food exclusively of fat there is a very small diminution in the elimination of nitrogen. In the case of a food exclusively of carbohydrates there is always an appreciable elimination of nitrogen. Hence the body eliminates nitrogen whatever may be the food qualitatively or quantitatively. Hence, to maintain, a body in nitrogenous equilibrium it is necessary to give proteid.

The quantity of meat which an animal can decompose in nitrogenous equilibrium has two limits, a lower limit and a superior limit, which represent the greatest quantity of meat which the animal is able to ingest, digest and absorb without causing trouble. These two limits are difficult to fix, as the lower limit depends on the state of fat and carbohydrates in the tissues and the superior limit upon the number of meals and the state of the digestive apparatus. Nitrogen equilibrium can be established by proteoses.

Phosphorus and thyroid extract increase the elimination of nitrogen.

In making a nitrogen equilibrium the substitution of carbohydrates for fats always acts better on the nitrogen balance than the substitution of fats for carbohydrates. Forced feeding by the addition of proteid increases the storage of proteid material in the body. Hence in wasting diseases of the body large amounts of proteid with some nonnitrogenous food must be given if the proteids and fats are to be increased.

Chittenden states that if an animal is in a state of nitrogen equilibrium by excessive proteid feeding, if suddenly given a small amount of meat per day it tends to put out nitrogen from its tissues. This tissue loss increases slowly, and eventually the animal is quite likely to establish nitrogen equilibrium at a lower level. In other words, there is a strong tendency for the body to pass into a condition of nitrogen balance under different conditions of proteid feeding.

When proteid is taken in a body in nitrogen equilibrium, a part goes to the repair of the organized proteid which is breaking down, another part will replace the unorganized proteid which has been catabolized, whilst the remainder remains in the tissues as unorganized proteid to be used. There is no reason to think that any proteid is stored in the shape of extractives.

In the retention of proteid in a surplus of proteid diet, in the adult, there is here an increase in volume of the individual cells of proteid and not an increase in their number. This increase of proteid in the body from a surplus of proteid does not remain when the person returns to his usual diet.

Alcohol can be substituted for equivalent quantities of carbohydrates or fats; that is, can protect them from oxidation. The utilization of the different foodstuffs is not affected by alcohol. Alcohol spares proteid less than carbohydrates when both are given in iso-dynamic quantities, but we do not use alcohol to spare the proteid but the fat of the body.

When the nitrogen excreted is at constant level and more water is drunk, if diuresis ensues more urinary nitrogen is excreted. Here the nitrogen in the urine is increased because the tissues are more thoroughly washed out. It is a flushing of the nitrogenous end-products and not an unusual breaking up of proteid. The lessening or withdrawal of water did not cause an increase in the consumption of oxygen. The extractives in the organs without fat are increased by thirst.

An Example of Nitrogen Equilibrium Without Carbon Equilibrium.—(Arthus.)

Ingesta.

	N.	C.
137 gr. proteids	19.5	315.5
117 gr. fats	0	
352 gr. carbohydrates	0	
	19.5	315.5

Egesta.

	N.	C.
Urine	17.4	12.6
Fæces	2.1	14.5
Respiration	0	248.6
	19.5	275.7

An Example of Nitrogen and Carbon Equilibrium.—(Arthus.)

Ingesta.

	N.	C.
100 grams proteids	15.5	53.0
100 grams fats	0	79.0
250 grams carbohydrates	0	93.0
	15.5	225.0

Egesta.

	N.	C.
Urine	14.4	6.16
Fæces	1.1	10.84
Respiration	0	208.00
	15.5	225.00

In an animal receiving an excess of carbon and nitrogen up to the point that catabolism equals anabolism, there is a greater deposit of both in the body the greater the amount of food given. There is thus a remarkable adaptation of the body to the diet which it receives, and the more or less rapid realization of the nitrogen and carbon equilibrium.

Example of a Metabolism Experiment, taken from Atwater.

The following table after Atwater contains a summary of the ingesta and excreta in an experiment with mixed food. The experiment lasted four days, the subject being a man thirty-two years of age and of about 64 kilograms body-weight, who remained as quiet as possible throughout the experiment.

Ingesta, mean weight in g. per day

Articles of Diet	Total weight	Water	Proteid	Fat	Carbohydrate	N.	C.	H. in organic substance
Meat	160	105.6	44.5	6.7	......	7.1	28.4	4.2
Butter	70	7.4	0.8	59.9	......	0.1	43.8	7.1
Skimmed milk	450	405.9	17.1	0.5	22.5	2.8	19.6	2.8
Maize, breakfast food	50	2.9	5.5	4.2	36.5	0.9	22.4	3.2
Sugar	64	......	......	......	64.0	......	26.9	4.2
Pepper Cake	30	1.4	2.0	2.5	23.3	0.3	13.2	2.0
Water	1,500	1,500.0	......	......	......	......	......	......
Bread	310	129.3	24.5	8.7	143.5	3.9	84.7	12.7
Total	2,634	2,152.5	94.4	82.5	289.8	15.1	239.0	36.2

Excreta, mean weight in g. per day

Articles of Diet	Total weight	Water	Proteid	Fat	Carbohydrate	N.	C.	H. in organic substance
Fæces	54.7	40.6	5.4	3.7	3.2	0.9	7.4	1.0
Urine	1,449.5	1,403.1	......	......	......	16.2	12.2	3.5
Respiration and skin	......	962.8	......	......	......	......	207.3	......
Total	......	2,406.5	......	......	......	17.1	226.9	4.5
Balance	......	— 254.0	......	......	......	— 2.0	+ 12.1	+ 31.7

"If we consider the fæces as pure loss, the body has disposed of (94.4 g. ingested — 5.4 g. excreted =) 89.0 g. proteid containing (16.2 — 2.0 =) 14.2 g. N, besides (82.5 — 3.7 =) 78.8 g. fat, and (289.8 — 3.2 =) 286.6 g. carbohydrates. In the urine 16.2 g. N were given off; but 2.0 g. of the N have come from the body itself—*i.e.*, (6.25 × 2 =) 12.5 g. of the body's proteid has been lost. The total proteid metabolism, therefore, has been (89 g. + 12.5 =) 101.5 g. (or 16.2 × 6.25).

"The ratio of N to C contained in proteid is 1:3.28. In the proteid destroyed by this man therefore there were 3.28 × 16.2 = 53.1 g. C. The total quantity of C eliminated in the respiration and in the urine was 219.5 g.; there remain 166.4 g. which must have been derived from nonnitrogenous food.

"Of carbohydrates 286.6 g. (289.8 ingested — 3.2 excreted) were absorbed from the intestine, and this by calculation was found to have contained 124.7 g. C. Now we shall see later that carbohydrates burn in the body more easily than fat. We therefore deduct *first* the C belonging to carbohydrate. This leaves 41.7 g. C (166.4 — 124.7) which must have come from fat—*i.e.*, since the fat used contained about seventy-six per cent C, 54.6 g. fat were burned in the body.

"We conclude that the body has decomposed a mean quantity of 101.5 g. proteid, 54.6 g. fat and 286.6 g. carbohydrate per day. Comparison with the ingesta, having regard to the C resulting from proteid destroyed, shows that the body has lost 12.5 g. of its proteid but has stored up 24.2 g. fat, containing 12.2 + 6.5 g. C." (Tigerstedt.)

Fasting.

After the first day of fasting hunger is felt, but it shortly vanishes. Water is not very necessary, and man in fasting gives out more water than he takes in. The pulse decreases, the temperature of the body stands at normal until the last few days before death by starvation. The weight of the body gradually lessens. During the first day of the fast the glycogen disappears. In man with an abundant supply of fats, the destruction of proteid gradually declines day by day. In animals scantily fed after a temporary fall of proteid metabolism there ensues a rise of metabolic changes of proteid. At the end of a fast when food is given the body lays down proteid and fat in large quantities. In fasting the body lives upon its own substance.

Benedict has recently made a thorough study of the effect of starvation on man. The daily loss of weight was from 44 grams to 1.7 kilograms. The body-temperature in general remained practically constant during fasting, with a smaller amplitude of the curve than usually is the case with man consuming food even under like conditions of muscular activity. In the thirty days of a fast by Succi the temperature was normal. The temperature only falls a few days before death. The pulse-rate as the fast progressed showed a distinct tendency to fall. The blood examination showed (1) a progressive average fall in the number of erythrocytes; (2) a corresponding diminution in the percentage of hæmoglobin; (3) a relative progressive fall in the percentage of leucocytes in the prolonged fast. But there was no remarkable effect of fasting on the relative percentage of the various types of leucocytes. Tests of strength showed a noticeable falling off when determined by the dynamometer. The nitrogen output varied considerably from 5.8 grams on the first day of one experiment to 15. grams on the third day of another experiment. The output of nitrogen was rarely below 10.5 grams per day. Of special significance is the fact that the nitrogen excretion on the second day was on the whole much greater than on the first. Of great significance is the fact that while the quantities of preformed creatinin increased as the fast progressed, the total creatinin remained singularly constant. From the first two days the uniformity in the carbon elimination was striking; as the fast progressed there was a rather persistent decrease in the output of carbon dioxide.

The amount of heat produced during Benedict's experiment was not far from 2,000 calories on the first two days of the fast. On the whole there was a slight increase in the amount produced on the

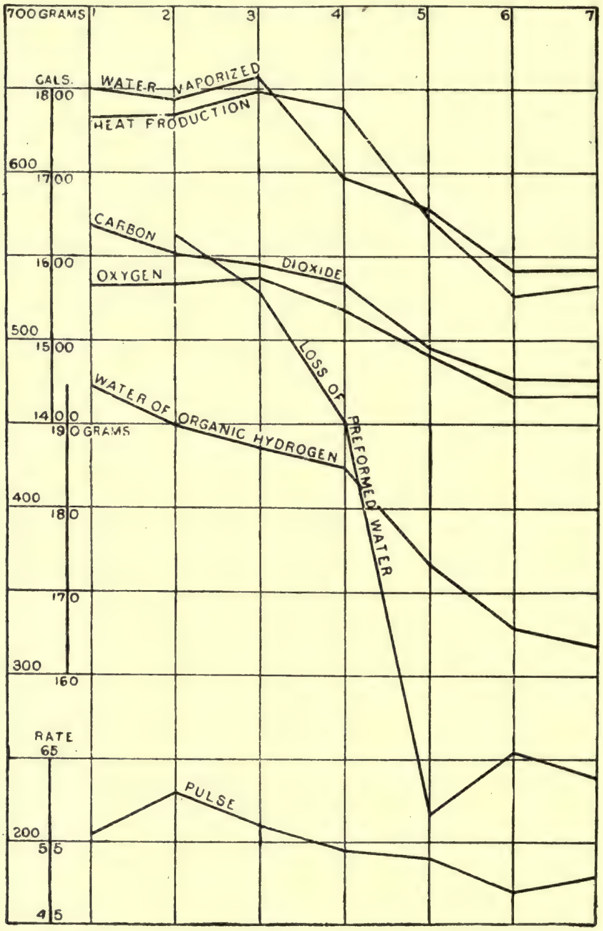

Fig. 178c.—Catabolism, Heat Production, and Pulse Rate During a Seven Day Fast. (Benedict.)

second day of fasting, but in the experiments which continued beyond two days there was a tendency for the heat-production to decrease as the fast progresses. The lowest measured amount was 1,548 calories on the fifth day of the second experiment, which was probably the minimum heat-production of this subject during fasting.

The quantity of proteid metabolism in starvation depends upon the amount of fat in the body. In the fast of Succi, Luciani found that a nitrogen excretion of 16.23 grams decreased on the first day of fasting to 13.8, on the seventeenth day to 7.8 grams, on the twenty-second day to 4,75 grams, on the twenty-eighth day to 5.6 grams.

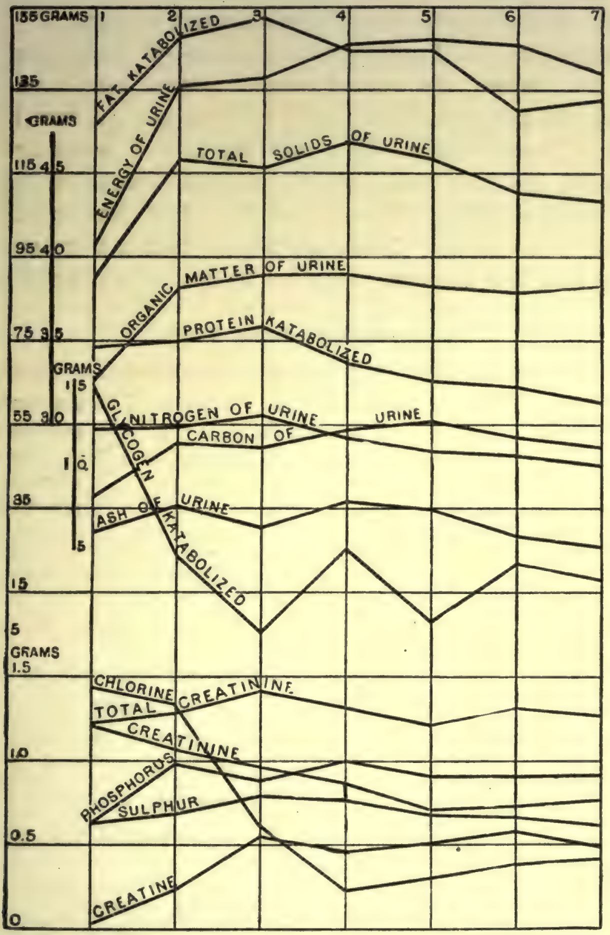

Fig. 178*d*.—Catabolism During a Seven Day Fast. (Benedict.)

Paton gives the following table to show that during the first day or two of a fast the individual uses proteids and fats as usual, but gradually he uses less and less proteid each day. This was the case in the fast for thirty days by Succi:—

Day of Fast.	*Proteid in Grams.*	*Fat Used.*
1	104	Not estimated
10	51	170
20	33	170
29	31	163

Here the stored fats were the chief source of energy.

In starvation the heart wastes but little—it lives upon the proteids in the tissues; the central nervous system loses 3 per cent. of its weight; 97 per cent. of the fat is used up, and the muscles lose 30 per cent. of their weight. If a starving man is suddenly supplied with proteid food, the man is unable to avail himself of the proteid so abundantly supplied, for only a small part of the proteid ingested is retained or stored up. Hence the fasting man can replace his proteid losses in a slow manner, even when he has an abundance of meat.

Composition of the Body.

An analysis of a body, as a whole, is represented as follows:—

Water	64 per cent.
Proteids	16 per cent.
Fat	14 per cent.
Salts	5 per cent.
Carbohydrates	1 per cent.

The constituents of the body must be constantly replaced by foods. To determine the quantity of the different foods required, is a study of diets.

Diet.

The diet of a healthy man has for its aim not only to cover any deficit without catabolism ceasing and of maintaining the system in a state of integrity indispensable to its physiological functions. It also must furnish to the organism a certain food reserve so that the body will not lose its own proper tissue. To ascertain exactly the quantity of nourishment necessary to keep the body-weight the same, it is necessary to have recourse to experiments.

Proteids contain about	16	per cent.	nitrogen.
	52	"	carbon.
	7	"	hydrogen.
	23	"	oxygen.
	0.5	"	sulphur.

Carbohydrates contain	carbon	44	per cent.
	hydrogen	6.2	"
	oxygen	49.4	"
Fats contain	carbon	76.5	per cent.
	hydrogen	11.9	"
	oxygen	11.5	"

Basal Requirements.

The basal energy exchange is inversely proportional to the weight of the body and directly proportional to the body surface. The condition of the body also has an influence on the basal requirement. Any special consumption of either fat or carbohydrate in the body metabolism is indicated at once by a corresponding change in the respiratory quotient.

The Energy Requirement of an Adult.

The minimal requirement, according to Atwater, for a man at rest is 2,241 calories. Hence a ration which does not supply 2,000 calories net must be inadequate for a laborer, for a waste of 10 per cent. must be deducted from the calculation in determining the net requirement.

In an atmosphere of a temperature of from 30 to 35 degrees C. the minimal requirement for energy is seen. The effect of temperature on metabolism is not due, according to Voit, to rigors or to increased respiratory muscular activity. He believes it to be the reflex stimulus of cold on the skin which raises the metabolic activity of the muscles.

The amido-acids resulting from the breaking up of proteids are equivalent in metabolism to the ingested proteid itself.

As regards the effect of temperature on metabolism, Rubner gives two laws, which have been summarized by Lusk:

First.—The first law is that within limits normally compatible with life, warm-blooded animals are capable of adapting themselves to change in external temperature through a reflex increase or decrease of activity of their heat-producing apparatus. For every state of body substance and for every temperature of the environment there is a definite amount of heat-loss to which the organism, with the aid of its heat-regulating apparatus, tends to approach.

Second.—The second law is that physical regulation can never enter as a factor unless the conditions of the first law are fully satisfied; that is, until the heat-production equals the requirement of the organism. If, however, the heat-production be greater than corresponds to the minimal requirement for that temperature, then the heat-production within certain limits remains independent of the temperature. Under these circumstances the heat-production does not decrease on raising the external temperature, and only increases when, through increasing cold, the former heat-production no longer covers the minimal requirement of the organism for heat.

The second law explains why in certain cases after food ingestion the carbon dioxide excretion may remain constant with changing temperatures. The increased heat-production on account of the specific dynamic action of the proteid was lost through the increased evaporation of water.

To determine the energy-value of foods it is necessary to admit that the proteids, fats and carbohydrates undergo complete combustion, the fats producing carbonic acid and water, the proteids carbonic acid, water and urea. The mean value is expressed in calories:—

One gram of fat when burned produces about 9.3 Calories.
One gram of proteid when burned produces about 4.1 Calories.
One gram of carbo-hydrates when burned produces 4.1 Calories.
One gram of alcohol when burned produces 7 Calories.

One large kilogram calorie equals 100 small calories. The large Calorie is written with a capital C; the small gram calorie with a small c.

Isodynamic Equivalent.—Rubner has shown that the different organic materials for food can replace one another in isodynamic quantities; that is, in quantities which yield equal amounts of calories. The ratio or isodynamic equivalent is as 9.3 to 4.1, or 2.3 to 1. Hence one part of fat can be used instead of 2.3 parts of carbohydrates as sugar.

From the point of energy-value, 100 grams of fat are equal to about 225 grams of proteids or carbohydrates. In this way we calculate the energy-value of our foods. A great number of analyses have shown that about 10 per cent. of the foods are not absorbed; hence some calories are lost, and must be noted in making up the number of calories needed in making out a diet table.

In the natural diet of the average man the carbohydrates represent two-thirds of total energy and the other third represents in equal parts the proteids and fats. This division of energy from the three kinds of food is the same for a person who rests or who does work. This is a remarkable fact, and indicates that the organism is able by work to utilize these three kinds of food, 25 per cent. of which energy is transformed into mechanical work, and 75 per cent. of which energy is transformed into heat.

At different periods of life (1) the proportion of proteid remains nearly constant in the diet; (2) in the nursling the fats in the diet give half the total energy in the nursling, in the infant a third and in the adult a sixth; (3) the carbohydrates furnish a third of the total energy for the nursling, a half for the infant and two-thirds for the adult.

In order to establish a rational diet for a man we must remember the isodynamic principle of foods that have the same caloric value. It suffices to furnish the organism with a sufficient number of calories, provided three conditions are fulfilled:[2] (1) It is necessary to determine the digestibility of the food, for only the absorbed foods furnish the energy; (2) it is necessary to count the need of a minimum of nitrogen; (3) the quantity of food ingested should not exceed the digestive capacity and cause trouble. A man cannot live exclusively on meat, for after many days there will be vomiting and diarrhœa; a man cannot eat potatoes alone, for the quantity ingested would be such that the digestive tract would not tolerate it. Suppose it is necessary to give a diet which will furnish 2,700 calories, and as one-tenth will not be absorbed, we will have to furnish a food whose caloric value is 3,000. In giving him 100 grams of proteids we will satisfy greatly his need of nitrogen; these 100 grams correspond to 410 calories. Still we need 2,599 calories, which we can furnish by 278 grams of fat or 632 grams of carbohydrates, or a convenient mixture of fats and carbohydrates.

In determining the proportion of fats and carbohydrates we must note the following facts: (1) The digestive tract does not work well with large doses of fats, it supports better carbohydrates; (2) on the other hand, the carbohydrates are less costly than fats. Hence it is practically advantageous to diminish the quantity of fats and increase the carbohydrates. In practice we usually take one gram of fat to ten grams of carbohydrates in the food of poor people, and one gram of fat to five grams of carbohydrates in the diet of wealthy people. Hence to furnish the 2,700 calories demanded we would use the following diet:—

100 gr. proteids	410.0	calories.
55 gr. fats	511.5	
507 gr. carbohydrates	2078.7	
	3000.2	(ARTHUS.)
Loss of 10 per cent	300.0	
	2700.2	

Dr. W. S. Hall's balance sheet for man at light work is as follows:—

		Income in calories.
Proteids	110 grams x 4100	451,000
Fat	100 grams x 9400	940,000
Carbohydrates	400 grams x 4180	1,672,000
		3,063,000

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[2] Arthus: "Eléments de Physiologie," 1905.

Expenditure :—

	Expenditure in calories.
1. Mechanical work, 212.750 kilogram meters.. (425.5 gram meters equivalent to a calorie.)	500.00
2. Heat lost in 2340 grams of excreta.......... (Cooling from 37° C. to 12° C.; 2340 x 25.)	58.500
3 Heat required to warm 13,000 grams of air from 12° C. to 37° C................... Specific heat of air, 0.26: (13.00 x 25 x 0.26.)	84.500
4. Evaporating 330 grams of water from lungs.. (1 gram requires .582 calories.)	192.000
5. Evaporating 660 grams of water from skin..	384.000
6. Radiation and conduction from skin, about..	184.000
	3,063.000

Atwater concludes that the energy requirements of the diet vary as follows :—

	Calories.
Man without muscular work......................	2700
Man with light muscular work....................	3000
Man with moderate muscular work................	3500
Man with severe muscular work...................	4500

Chittenden made experiments upon soldiers and athletes for six months. The 118 grams of proteid necessary per day, according to Voit, means at least 16 grams of nitrogen in the urine, when this food is metabolized in the form of urea, uric acid and purin bases. Minkowski has shown that adenin, one of the purin bases found in the breaking down of cell-nuclei, has a marked toxic action on dogs and man. It has a local action on the kidneys, giving rise to deposition in the kidney itself of spheroliths of uric acid or urate, which leads to acute nephritis, albuminuria and speedy death of the animal. The alloxuric bases also cause fever, when given by the mouth or subcutaneously. It is evident that the products of proteid metabolism are more or less dangerous to the body, especially so when there is an excess of proteid food consumed. Chittenden reduced the food of the soldiers one-half to one-third of the amount ordinarily considered necessary. After the body had once adjusted itself to these new conditions, the body-weight remained at a stationary condition. There was a marked increase in physical strength; there was no falling off in physical or mental vigor, or any change in the hæmoglobin or in the number of erythrocytes. An excess of proteid over that which is really needed for these purposes causes so much unnecessary strain upon the organism. It imposes a needless labor on the excretory organs. Moderation in the taking of proteid foods means a great saving in the wear and tear of the body machinery, especially the kidneys and liver, and a lessened production of uric acid.

A vegetable dietary is not desirable, for the vegetable proteids in decomposition differ much more in amido-acids from the serum proteids than the animal food proteids. Hence a mixed diet, having proteids of varying composition, is needed, for the absence of amido-acids in a food proteid can be replaced by another food proteid having a comparative excess of the same amido-acids.

Benedict concludes that Chittenden's permanent restrictions of proteid ingested is decidedly disadvantageous and not without possible danger. Magnus Levy does not believe that the products of nitrogenous decomposition are injurious to a healthy man, or that the toxines formed in the intestinal canal from an excessive proteid diet are so dangerous as they are held to be. In cases of disease of the liver or kidneys or nervous system, the excess of proteid may be injurious.

Tigerstedt[3] states that a man can perform work and be in nitrogen equilibrium on a less quantity of proteid than held necessary by Voit. But it does not follow from these experiments that proteid should be diminished. He holds that the diet should contain a sufficient quantity of proteid.

Rubner believes that meat is the best proteid for the masses. He considers that for a person who worked for an average number of hours daily, the amount of albumin should be 131 grams, whilst 118 grams must be regarded as the minimum. The excess over the amount necessary in the laboratory experiment serves partly as a safety valve and partly to cover the needs of heavier work.[4]

Förster also states that fats could not be utilized to a full extent as long as the body was kept on a minimum of proteid. Animals which were underfed for a considerable period could not always be refattened. He also noted the diminished production of agglutinins during underfeeding.[5]

Leathes states "the food of an infant in the second half of the first year is commonly and normally about two pints of milk. Even taking this to contain only 1.5 per cent. of proteids, that gives 17 grams daily, or 2 grams per kilogram, and this estimate, which is certainly not high, is more than the conventional adult diet provides and from five to ten times as much as the minimum. It is indeed a well-known fact that the rate of urea excretion in infancy is higher in proportion to the body-weight than at any other period of life. If ten times the minimum rate is the normal diet provided by nature, then even after making full allowance for the necessities of growth, the minimum can hardly be normal for the adult nor the amount ordinarily taken a very great deviation from the prescriptions of nature."

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[3] Untersuchungen über die Ernährung der Landvölkerung in Finnland von Sigfrid Sundström, 1908.

[4] British Med. Jour., p. 1077, 1907.

[5] British Med. Jour., p. 1077, 1907.

Albertoni and Rossi found that when the Italian peasants, with a diet from birth of vegetables only, had proteid added, that there was an increase of hæmoglobin, the number of red corpuscles augmented, the strength of the body was greater, and their ability to perform their various duties was greater. Their psychical functions were also better.

Baron Kakaki showed that a disease called kakke disappeared from the Japanese navy when the proteid in their diet was increased. These men previously had an excess of carbohydrates in proportion to the proteid. Other diseases also were less with the increase of proteid diet.

Metabolism in Fever.

There is an increase of proteid destruction during fever. The creatinin excretion is also augmented, but not to the same extent as the total nitrogen excretion. This increase of proteid metabolism is due to the toxines of the bacteria in great part and not to the increase of temperature. Rolly found the amount of glycogen diminished in toxic fever and in fever due to puncture, or what is called neurogenic fever.

Hirsh, Müller and Rolly hold that in an infectious fever we have two parallel processes: (1) a specific toxic breaking down of proteid by the bacteria, and (2) a central excitation in the sense of a neurogenic fever. Ott and Scott have made a number of experiments upon glycogen-free rabbits with B.-tetra-hydro-naphthylamin, which produced a fever. This fever is neurogenic, as it does not ensue after a section behind the tuber cinereum. Here the drug must have produced fever through an action on the proteids, as no glycogen was present. Rolly found in glycogen-free rabbits that puncture of the corpus striatum, a thermogenic center, caused no fever. We think that the puncture was simply too weak a stimulant to the enfeebled thermogenic center of a rabbit starved and exercised by strychnia spasms.

When a more powerful chemical stimulant, as the naphthalin compound, was used then fever was produced in the glycogen-free rabbit. In neurogenic fever there is an increased excretion of urea.

Nearly all observers agree that in fever there is an increasing proteid metabolism, but no increased fat metabolism except such as may result from inanition in the individual. There is every reason to believe, in the puncture of the thermogenic centers and in infectious fevers, that they both produce fever by an action on the thermogenic centers. As Aronsohn has contended, there is no toxic destruction of proteid except through the trophic nerves of the thermogenic centers. The intracellular ferments also have a share in the metabolic changes of fever.

An increased destruction of proteid ensues in fever where there is a paucity of glycogen and fat. The same series of metabolic changes ensue in both infectious and neurogenic fever.

Obesity.

Obesity is produced by all the causes which slow the organic oxidations, as sedentary life, absence of work or locomotion, and insufficiency of air and light. Predisposing causes are heredity, anæmia and sexual influences. Alcohol is not the direct cause of obesity, but causes it by sparing the fat combustion in the diet.

There is a method of reducing obesity known as Banting's method, named after an Englishman of that name. The method is to eat almost exclusively proteids, the patient obtaining his fat in his body, although some fat is produced by the proteids.

In the Oertel method of treating obesity, the cardiac muscle is strengthened by diminishing the amount of food one-half and of water still more, and by using carefully regulated exercise. The nitrogenous foods are in this plan increased, and the nonnitrogenous decreased.

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CHAPTER X.

ANIMAL HEAT.

INORGANIC bodies have a constant tendency, either by losing or gaining heat, to adapt themselves to the temperature of surrounding media or objects. They may be artificially cooled or artificially heated to all possible degrees.

Living plants and animals also receive and give off heat physically; but, in addition, they possess a common power of *resisting* external temperatures. With the plants this power is very feeble in degree; with animals it is more marked. Among the higher animals, especially, is there an inherent power to maintain a temperature that differs from that of the surrounding media. Since living animals, like dead ones and inorganic bodies, exhibit the same physical phenomena of absorption, conduction, and radiation of heat, they undergo constant changes; these are usually in the direction of loss of heat. Hence there must exist within them a power of constant renewal or production of heat to take the place of that lost. This function of producing heat is universal with the warm-blooded animals, and all of the processes of life are influenced by it. Certainly the higher animals have within their bodies not only some means to produce heat, but some mechanism whereby the production and loss are regulated. Thus, though the temperature of the surrounding atmosphere be very high, as in midsummer, or very low, as in midwinter, yet the standard temperature of the animal's body remains uniform and constant. The energy necessary to accomplish this is known as *animal heat.*

Physical Heat.—Heat is a form of *energy* exhibited by matter. We cannot create or destroy either.

Energy is the power to do work. Any agent that is capable of doing work is said to possess this property. The quantity of energy that it possesses is measured by the amount of work it can do. When a body is hot it possesses a store of energy which may be exhibited by the heated matter.

Energy is known in *two forms:* 1. The energy possessed by a body in consequence of its *velocity* is known as *energy of motion,* or *kinetic energy.* The body in motion which has this kinetic energy communicates it to some other body during the process of bringing it to rest. This is the fundamental form of energy.

2. The other form of energy which a body may have depends not upon its own state, but upon its *position* with respect to other bodies. It is the energy possessed by a mass in consequence of its having been raised from the ground. Potential energy can exist in a body, all of whose parts are at rest.

Rubner and Atwater have shown that the law of conservation of energy is also applicable to the living body. The metabolism of the food and tissues liberates their stored energy and converts it into heat and motion.

Radiant heat is one and the same thing as that which we call *light*. When detected by the thermometer or by the sensation of heat, it is called radiant heat.

When equal weights of quicksilver and water are mixed together, the resulting temperature is not the mean of the temperature of the ingredients. The effect of the same quantity of heat in raising the temperature of two bodies depends not only on the amount of matter in the bodies, but also upon the kind of matter of which each is formed. This is called *capacity* of *heat*, or *specific heat*.

The capacity of a body for heat is the number of units required to raise that body one degree of temperature. The specific heat of a body is the ratio of the quantity of heat required to raise that body one degree to the quantity required to raise an equal weight of water one degree.

Latent heat is the quantity of heat that must be communicated to the body in a given state to convert it into another state without changing the temperature. Avery describes it as follows:—

The latent heat of a substance is the quantity of heat that is lost to thermometric measurement during liquefaction or vaporation, or the amount of heat that must be communicated to a body to change its condition without changing its temperature.

The higher the temperature of a body, the greater is its radiation. When the temperature of bodies is unequal, the hotter bodies will emit more heat by radiation than they receive from the colder. Therefore, on the whole, heat will be lost by hotter and gained by colder bodies until thermal equilibrium is attained.

The cause of heat is popularly explained to-day by what is known as the *"undulatory theory."* According to this doctrine the heat of a body is caused by an extremely rapid oscillating or vibratory motion of its molecules. The hottest bodies are those in which the vibrations have both the greatest velocity and the greatest amplitude. Hence, heat is not a substance, but a *condition* of *matter*. It is a condition which can be transferred from one body to another. When a heated body is placed in contact with a cooler one, the former gives more molecular motion than it receives; but the loss of the former is the equivalent of gain of the latter.

Animal Heat.—Within the organs of the human body, as well as those of all animals, processes of oxidation are continually going on. Oxygen passes through the lungs into the blood to be thus carried to all parts of the body. In like manner the oxidizable bodies, which are principally foods, pass by the processes of digestion into the blood finally to reach every part of the body. The gases, liquids, and solids which enter the body are loaded with energy. These various bodies are intimately concerned in the different chemical processes which sum up metabolism: that is, those phenomena whereby living organisms are capable of incorporating into their tissues, substances obtained from their food. Metabolism is also concerned in the formation of a store of potential energy which may readily be transformed into *kinetic energy,* as manifested in muscular work and heat. Within the body the assimilable substances undergo many chemical changes, and finally leave it in forms quite different from those on entering it. The oxygen inspired combines mainly with carbon and hydrogen to form carbon anhydride and water, while the more complicated compounds are reduced to simple bodies, to be excreted as such. In the process of disintegrating these compounds —in fact, in catabolism in general—one of the most important results is the *production* of *heat.* The energy enters the body as potential energy stored up in the food. By chemical processes it becomes evolved into kinetic energy and heat. Animal heat is the accompaniment of the formation of carbonic acid, urea, and other excreted products. According to our theory of heat, the animal heat due to metabolic processes must represent to us vibrations of the corporeal atoms.

Other Sources.—Roughly speaking, the muscles constitute about one-half of the whole mass of the body, the bones the other half. As but little oxidation occurs in the bones, the muscles must be the chief seat of heat-production. Muscular exercise greatly increases the metabolism and the CO_2 excreted, but there is an accompanying increase in heat-production. In health the muscles yield *four-fifths* of the body heat.

The *secreting glands* are known to be centers of thermogenesis as well. The alimentary canal during digestion and also the liver are very marked sources. In fact, the blood in the hepatic veins is the warmest part of the body. The function of the muscles, tendons, ligaments, and bones is not a very slight source of warmth.

It must be borne in mind by the student that the processes of oxidation are concerned not only in the combustion of the digested foodstuffs, but also of the *cells* of the body. It is the oxidation of their protoplasm that evolves warmth.

Warm-blooded and Cold-blooded Animals.—Depending upon the relationship of the temperature of the animal's body and that of the enveloping media there are two great classes: *homothermal* and *poikilothermal.*

The *homothermal,* or warm-blooded, animals include the higher orders of the animal kingdom, in whom the temperature remains fairly constant despite variations in temperature of the enveloping media. The temperature of this class of animals is high, but uniform. Should homothermal animals remain for a considerable length of time in a cold medium, their heat-producing organs become more active in order to compensate for that lost rapidly by radiation. When they remain in very warm media, heat-production is diminished.

Poikilothermal, or cold-blooded, animals constitute that class of lower animals whose temperature bears a very intimate relationship and is dependent upon that of the enveloping media. Their temperature is thus subject to very considerable variations, although it is always *slightly above* that of its surroundings. When the temperature of the surrounding medium is raised, the amount of heat produced within poikilothermal animals is increased. Inversely, when the enveloping temperature falls, the heat-production within the animal is diminished. This class includes reptiles, amphibians, fish, and most invertebrates.

However, the line of demarkation between the two classes of animals is not a very clear and decisive one. For there are some animals, as the bat and dormouse, which seem to be intermediary. In summertime they possess a high temperature that is independent of their surroundings; in winter they become dormant and hibernate. While in this latter condition their temperature varies with that of the enveloping medium.

Temperature of Man.—Although the blood in circulation tends to distribute the heat of the body uniformly, yet there are found slight variations in different regions. These regions are principally upon the surface, where exposure is such that the leveling function of the blood is hindered. The mean, daily temperature of a healthy man varies between 98° and 99° F. In the rectum it is 98.96° F.; in the axilla, 98.45° F.; in the mouth, 98.36° F. These figures represent the averages obtained from various observations, but they, too, are subject to various variations from exercise, rapid respiration, food within the alimentary tract, etc.

From frequent observations and numerous tables it will be found that the mean rectal temperature of *other mammals* is, for the most part, higher than that of man. In the case with birds, the temperature averages from two to three degrees higher than that of mammals. In securing these observations it is always necessary that the animal should not struggle either before insertion or during the time that the thermometer is in position. A faulty reading of as much as three degrees may occur when the animal struggles or has been previously chased.

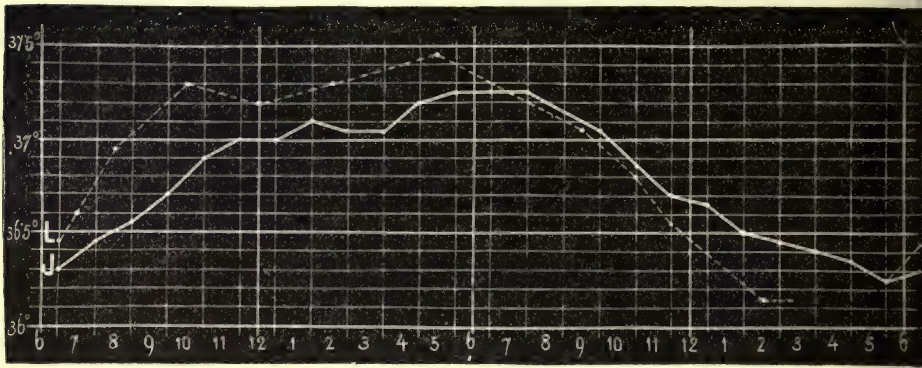

Fig. 179.—Variations in the Bodily Temperature during Health within Twenty-four Hours. (Landois.)

L........according to v. Liebermeister. J———according to Jürgensen.

Hibernation.—Many animals regularly at the approach of cold weather gradually lose their activities until they apparently have lost all of their functions and are dormant. Such a state is known as *hibernation*. The temperature of the animal's body is but a trifle above that of the surrounding atmosphere. The respirations are greatly decreased in number, while the rhythm is of the Cheyne-Stokes type. The heart's action in point of force and frequency is much reduced during hibernation. Animals whose hearts during active life beat one hundred or more now register but *fourteen* or *sixteen* per minute. The digestive powers are at a very low ebb, while as to its nervous sensibilities the animal is very markedly depressed.

The *awakening* from hibernation is a most interesting phenomenon in so far as the rise of the animal's temperature is very sudden. So sudden is the rise and in so short a time is it accomplished that it surpasses the most rapid rise in temperature of any fever. With proportionate celerity are the vital functions spurred on to activity.

Modifying Influences.—Close observation shows that there occur slight variations in man's daily temperature. It is found to *rise* during the late morning and afternoon; to *fall* during the evening and early morning. Because of differences in age of subjects, modes of living, climate, etc., observers are not agreed as to the maximum and minimum temperatures. However, it may be safe to say that the maximum temperature is attained about from *3* to *5* o'clock in the afternoon, while the minimum is registered at from *3* to *5* o'clock in the morning. The range of difference averages about 1° C.

CAUSES.—Probably the two most important causes for these normal variations are *muscular activity* and *food-ingestion.* It is during the day that man, as a rule, is most active and it is then that he usually replenishes the waste of his body by the consumption of a proper amount of food. Naturally he will be most inactive during the night; his bodily functions will be depressed at that time so that just so much heat will be generated as the economy needs.

It has been found that the maximum and minimum points of temperature in man can be inverted. Thus, if a man change his mode of life so that he continue to *work* for a considerable length of time at *night* and sleep in the daytime, after a week's time there will be noted a gradual change toward inversion. It is well to note also that the high and low points of temperature of the body correspond to those times when the external temperature is high and low, respectively. Radiation may thus be a not inconsiderable factor.

Age.—Just before birth the infant's temperature is generally somewhat higher than that of its mother's uterus. After birth and during the first few weeks the temperature remains fairly constant, but still a little high. There is a fall of one-tenth or two-tenths from infancy to puberty; a like amount from the latter period to middle life, when there occurs a slight rise.

During *muscular work* the temperature rises rapidly, but, by reason of compensatory measures, the loss by radiation and conduction is almost proportionately increased. So nearly are the generation and loss balanced that during actual work there is registered but a rise of a degree and a fraction. With the conclusion of the muscular activity the temperature very rapidly falls to normal. *Mental work* causes a rise of both the general as well as local temperature of the brain and head. The increase registered is usually about 0.1° C.

Food causes a very slight rise in temperature; *sleep*, in itself, has no effect. *Inactivity* is a very marked factor in producing a fall. As inaction is very prominent during sleep, the latter has been erroneously given the credit for causing the drop in temperature. Lying perfectly quiet will produce identical results. Because of the heat, the inhabitants of tropical countries possess a slightly higher temperature. The difference is less than 1° C.

Extremes of Temperature.—During excessively hot spells in summertime when the temperature of the enveloping atmosphere is considerably above that of the normal body-temperature, it is remarkable to find that the temperature of the body has not been raised one degree. This result is mainly accomplished by reason of the heat extracted from the body's surface during evaporation.

The limit of extreme cold is reached when the lymph within the animal's tissues is frozen. Fishes have been incased within ice and then found completely recovered upon being thawed out and placed in a warmer medium. Normally, the range of temperature in a man is about 1° C. However, drunkards have been known, after exposure to extreme cold, to have a bodily temperature as low as 24° C. without fatality.

Cases of temperature as high as 45° C. have been noted and yet recovery has taken place. Experimentally, Bernard found that, when the internal temperature of rabbits was raised to 45° C., they died. According to his view, death occurred as the result of stoppage of the heart from the hot, circulating blood, causing *rigor mortis* of the musculature of this organ.

Temperature of the Blood.—The average temperature of the blood is 39° C., but there are found numerous variations in different regions. The blood of the superficial veins is cooler than that of the internal veins, due to prolonged exposure while traversing the course of the former. The warmest blood of the body is that of the *hepatic veins.* The blood in the veins is cooler than the blood in the corresponding arteries, due to the more superficial position of the former. The temperature of the blood of the left heart is somewhat lower than that of the right. This has been explained on the ground that the right heart is in closer proximity to the warm liver; also, that the blood going to the left heart has been cooled from its passage through the lungs during respiration.

Estimation of Temperature.—Our knowledge as to difference in *degree* of the heat of the same or different bodies is gained by thermometry. Thermometers are instruments for measuring temperatures. Their principle is based upon the physical phenomenon of *expansion of bodies by heat.* Liquids are best suited for this purpose. Mercury and alcohol are the only two liquids used.

The mercurial thermometer is the one most extensively used. It consists of a capillary *glass tube,* at the end of which is blown a *bulb.* Both the bulb and portion of the tube are filled with mercury. The expansion of the mercury is registered by a scale which is graduated either upon the stem itself or upon a frame to which it is attached. On the Continent, and more especially in France, the stem is divided into one hundred parts, or degrees; this division is known as the Centigrade scale. In England, Holland, and North America the Fahrenheit scale is used. Its stem is divided into two hundred and twelve degrees between zero and the boiling-point of water.

Estimation of Heat.—*Calorimetry* is the measuring of the quantity of heat which results from the transformation of energy. By it is learned the amount of heat possessed by any body, and what amount of heat the latter is capable of producing. Calorimetric measurements are expressed in *thermal units.* A certain quantity of heat with which all other quantities are compared is known as a *thermal,* or *heat, unit.*

A *thermal unit* is the quantity of heat required to raise a definite quantity of water from one defined temperature to another defined temperature. A particular thermal unit has been called by some authors a *Calorie.* It is the quantity of heat necessary to raise a kilogram (2.2 pounds) of water 1° C. An English heat unit is the quantity of heat required to elevate one pound of water 1° F. One Calorie equals 3.96 English heat units. In Germany scientists frequently use the word *calorie,* but mean the *gram-calorie.* It represents the quantity of heat that is required to elevate the temperature of 1 gram of water 1° C.

The whole science of animal heat is founded upon thermometry and calorimetry, as well as the indirect method of calculating the quantity of heat produced from the quantity of nutritive materials that have been consumed. There are various types of calorimeters in existence, but it has only been within the past few years that results at all exact have been attained.

The calorimeter employed by the author in his laboratory experiments is constructed as follows: It is composed of two cylinders of galvanized iron—one smaller than the other and inclosed within the larger. The space in which the man lies upon a mattress is six feet long and two feet in diameter. Air is conveyed to him through the tube (*H*) which traverses the whole length of the apparatus to enter the hollow tube of lead at *F;* it finally emerges at *B*, after having given off its heat to the water between the two cylinders. The meter (*M*) is run by the water-wheel (*N*), which aspirates the air through the entire apparatus by means of a hose (*R*) connecting it with the lead tube at *B*.

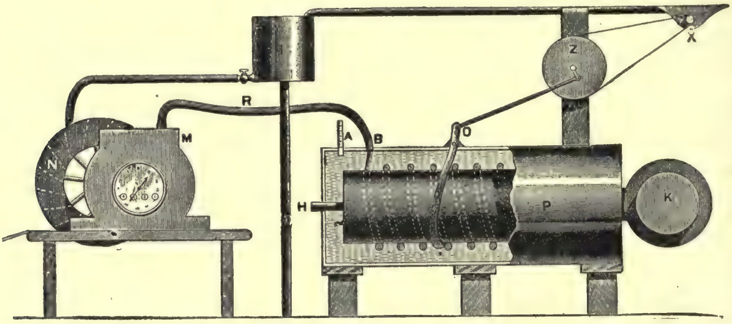

Fig. 180.—Human Calorimeter.

The space between the cylinders is filled with about 484 pounds of water. This water is kept thoroughly mixed by means of the agitator (*O*), which has two arms. The arms are pushing the water back and forth thirty times a minute, the motion being caused by the electrical motor (*X*), whose wheel (*3*), with its eccentric, drives the agitator. The thermometer (*A*) gives the temperature of the water; because of the thorough mixing of the water by the agitator it gives an accurate record of the temperature of the water throughout the apparatus. The thermometer is pushed down farther than is represented in the illustration. It usually lies aside of the tube (*H*). The air-tube (*B*) also has a thermometer to denote the temperature of the air as it is heated by the man. The thermometer at *B* is graduated into tenths, while that at *A* is graduated into fiftieths. The markings are so far apart that one one-hundredth of a degree Fahrenheit can be read.

The temperature of the mouth is taken by a thermometer graduated into tenths. The rectal temperature is preferable because of accuracy. The bucket (*I*) receives the water from the motor (*X*), and so conveys it to the water-wheel (*H*) that runs the meter as an aspirator. The meter is filled with water, and belongs to Voit's little respiration apparatus. The quantity of air that is aspirated within an hour is from 5000 to 6000 liters, which is ample for respiratory purposes. The instrument is made air-tight by means of the door (*K*), which is lined at its outer edge with rubber. The whole apparatus is inclosed in over six inches of sawdust, the door (*K*) having against it a sawdust mattress.

The door is bound by eight powerful screw-clamps. The air enters the tube (*H*), then passes through a leaden tube that is coiled upon itself before it reaches the person lying upon the mattress.

I have tested the calorimeter before and after the performance of my experiments.

The interior of the instrument is lighted up by an Edison incandescent light of one-candle power. The patient is thus enabled to spend his time in reading a book while the experimenter is making his observations.

By placing a pulley outside the calorimeter and attaching to a leather rope a fourteen-pound weight, the man within the instrument is able to exercise. The leather band enters one of the air-holes of the instrument. Of the entire amount of heat dissipated, about *14 per cent.* is thrown off by the lungs.

My little calorimeter is constructed upon the same plan as the instrument for men. In this—the animal calorimeter—the agitator sits astride the inner cylinder, outside of the leaden coils, and is run at the rate of sixty to seventy movements per minute by means of a water-motor. In other instruments the water is occasionally agitated by means of a hand-contrivance. Instead of the air entering the inner chamber by a straight tube, it traverses a tube coiled upon itself in the water reservoir of the instrument to enter the inclosure at its base. The air emerges through the opening at the top to be carried out through the serpentine coil and thence through the aspirating meter. The latter records at the same time the amount of air. The constant activity of the agitator causes the heat to be equally diffused through the water and so permits none to be given to the air. The door swings upon a hinge. In its center there is a glass through which one can readily see the state of the animal or the apparatus connected with it. At its edge it is lined with rubber and closed by powerful iron screw clamps. In front of the door is a mattress of sawdust several inches thick. Over and around the calorimeter, instead of the usual sawdust or felt, I used the packing material of wood-fiber known as excelsior. The whole instrument is inclosed within a box which has a door.

The calorimeter is sixteen inches in length and twelve inches in diameter. The instrument has a circular opening through which a thermometer graduated to one-fiftieth of a degree Fahrenheit passes into the water. An opening is also provided in the air-tube into which a thermometer can be inserted.

This instrument is fairly exact. By calculation it is found that the error is 5.4 per cent. After the performance of numerous experiments it was found that the variations from this number were within 1 per cent. Hence it may be assumed that this is an instrument of precision. For absolute accuracy the moisture of the air and the barometric correction should be made, but they would not alter the result very perceptibly. The instrument is always used with the air a degree or so above the temperature of the calorimeter. The agitator is set in motion for a half-hour before the observation is commenced. The room temperature for twenty-four hours previously is kept the same. With these precautions the instrument works accurately.

By the calorimeter we are enabled to measure the transformation of the potential energy of the food into heat and, at the same time, measure the number of heat units produced. The total amount of energy present in the human body might be measured by completely burning an entire human body in a calorimeter. By this means it may be determined how many heat units are produced when it is reduced to ashes.

If a man were not supplied with food he would lose fifty grams of his body-weight every hour. This is due to the constant oxidation which occurs, whereby the materials of the body unite with the inspired and circulating oxygen to produce combustion and *heat.*

It is known that any given oxidation will always produce the same amount of heat. Thus, if a gram of fat be burned in a calorimeter there will be produced a certain and almost unvarying number of heat units. By numerous experiments upon foodstuffs it has been determined by the calorimeter just the number of heat units a gram of each will yield. Just as in the calorimeter, only *far more slowly,* are the foodstuffs within our bodies burned up. That is, the presence of oxygen transforms the potential energy within them into kinetic.

Should the voluntary activities be at rest, the major portion of this energy is transformed into *heat.* The same number of heat units would be produced within the body as within the calorimeter, provided the foodstuffs were completely oxidized. However, we know that every gram of proteid yields one-third of a gram of urea during combustion within the body. The urea has a heat value of its own, so that the real number of heat units obtained by body-combustion is considerably less than that of calorimeter combustion of proteids.

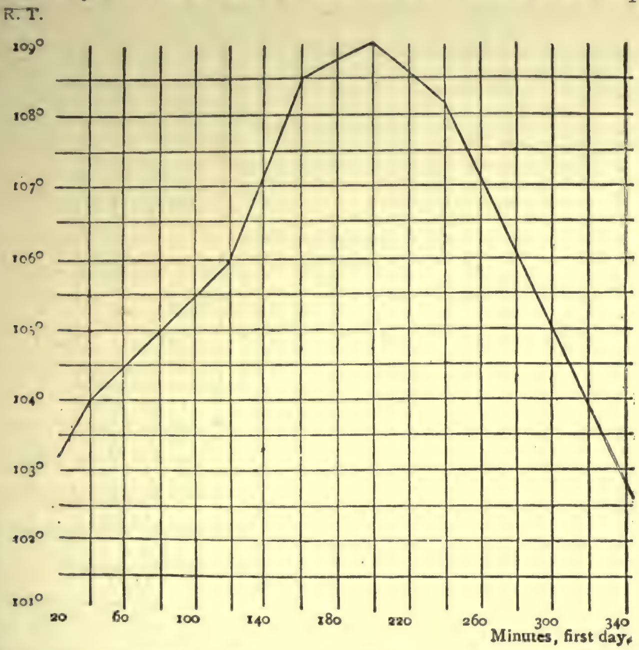

Fig. 181.—Bilateral Puncture of the Tuber Cinereum of Rabbit Through Roof of Mouth.

The units obtained from body or tissue combustion represent a "physiologic heat-value"; those gained from the calorimeter, a "physical heat-value."

A man produces daily a quantity of heat equal to about 2800 calories.

Regulation of Temperature.—That the regulation of the temperature cannot be accomplished solely by the action of the circulation, respiration, vasomotor, and sudorific centers, is shown by the following facts: (1) If a puncture is made through the roof of the mouth of a rabbit with a guarded dental drill and the tuber cinereum is only slightly grazed, the animal will fall at your feet, dead, in five minutes. If now the temperature is taken, it will be found to be $109^1/_2$° F. Here there is a sudden arrest of the circulation, respiration, and vasomotor action, in fact a rapid death, still the temperature rises to 109.5° F. Now, if by a puncture of the medulla, pons,

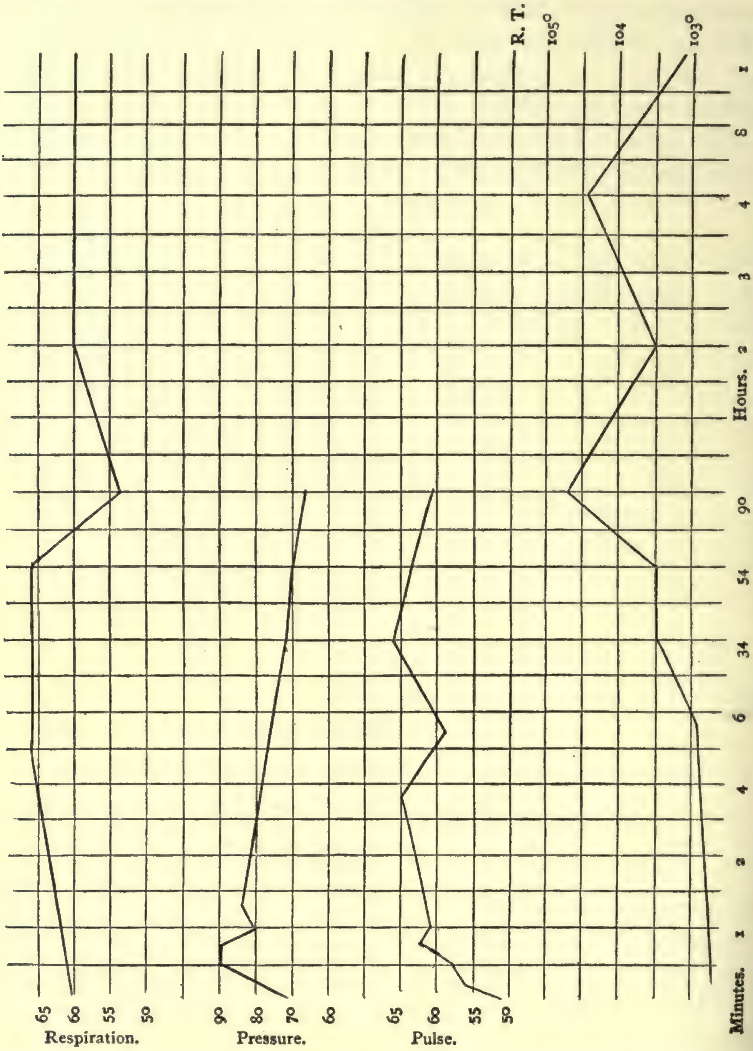

Fig. 182.—Puncture of Tuber Cinereum in Rabbit, Showing Effect on Respiration, Arterial Tension, Pulse, and Temperature.

At the end of 90 minutes the animal was unbound, when a rise occurred in curve of respiration.

or crura cerebri, sudden death ensues; yet the temperature is but slightly increased. These facts show that the injury of the tuber determines a rise of temperature by some action on the metabolism of the body. (2) When a rabbit is bound down and the respiration, blood-pressure, and pulse are recorded on the kymograph, and the thalamus punctured, then the temperature records its highest point at the time when the respiration, arterial tension, and pulse-rate are falling.

In a transverse section of the corpora striata, I have seen a temperature of 110° F. and the animal die inside of five minutes. Hence we must attribute the regulation of temperature to special thermogenic and thermo-inhibitory centers.

Thermotaxic Centers.—These centers compose the thermogenic, thermo-inhibitory, and thermolytic centers, as the aim of all is to regulate the temperature.

THERMOGENIC CENTERS.—*Spinal Cord.*—Destruction of the spinal cord from the fifth dorsal vertebra down permits the animal to generate as much heat as before the operation. A drug, beta-tetrahydronaphthylamin, when injected by the vein causes a great increase of temperature, but after a section behind the tuber cinereum it fails to cause any rise of temperature. These facts lead to the conclusion that there are no special thermogenic centers in the spinal cord, but that the basal thermogenic centers act through the trophic centers in the anterior cornua.

Brain.—When a normal animal is subjected to heat or cold it regulates its temperature and keeps it at a fixed point. If, however, the spinal cord is separated from the brain, the spinal cord is not able to regulate the temperature at a given degree, but its temperature changes with the temperature of the surrounding air. These facts show also the importance of the thermotaxic centers in the brain in the regulation of temperature.

As to the medulla oblongata and pons, numerous punctures by a probe two millimeters in width and one millimeter in thickness caused a very slight rise of temperature, which was of a very fugitive nature. Cross-section of the pons is an operation which cuts off the afferent and efferent fibers from the thermotaxic centers anterior to it and permits heat-production to increase without any regulation. If there are any thermogenic centers in the pons, puncture ought to bring out the fact, as it has done for the thermogenic centers located in the basal ganglia.

Any transverse section behind the crura cerebri or pons simply cuts out the thermogenic and thermo-inhibitory centers in front of the section and permits the thermic apparatus behind the section to elevate the temperature. That a greater rise of temperature should ensue after pontal than after crural section is quite in accord with the well-known fact that successive sections from before backward cause a greater activity of the spinal-cord centers behind the section, and also of the trophic centers.

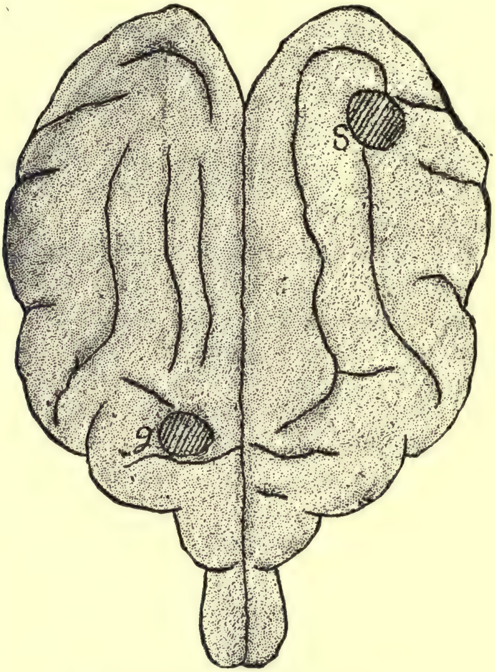

Fig. 183—Cortex of Cat's Brain.

g, Cruciate thermo-inhibitory center of Eulenberg and Landois. *S*, Sylvian thermo-inhibitory center of Ott.

Now, I have shown that after the intravenous injection of beta-tetrahydronaphthylamin in the normal animal a great rise of temperature ensues. But after section through the crura cerebri this drug is powerless to raise the temperature. A needle-point thrust into the pons or crura causes a fugitive rise, and a feeble one. But if the needle goes into the corpora striata or tuber cinereum there is a quite permanent and considerable elevation of temperature. To assume that a different kind of thermogenic center exists in the pons is begging the question.

In April, 1884, I was the first to make a transverse section of the corpora striata in the cat, which was followed by the temperature rising to $110^{1}/_{2}$° F. Afterward Drs. Sachs and Aronsohn more exactly localized the center in the caudate nucleus. I also located another thermogenic center in the optic thalami, a bilateral puncture of their anterior ends causing a rapid rise of temperature to 109° F. Von Tangl, of Budapest, has confirmed this fact by experiment upon the brain of a horse. Upon more exact localization this thalamic thermogenic center was found to be located in the tuber cinereum. Hence the conclusion that the thermogenic centers are located in the corpus striatum and tuber cinereum.

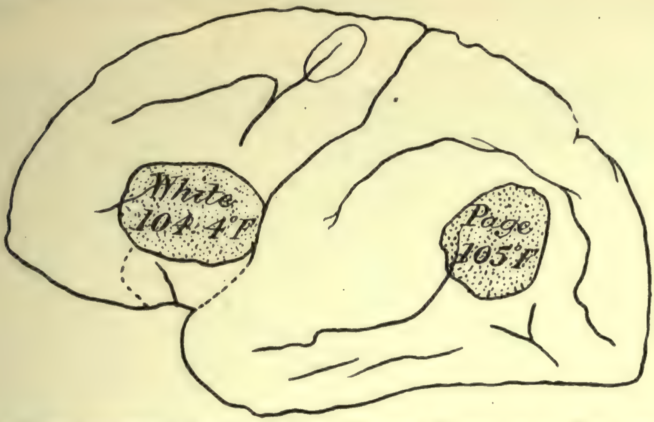

Fig. 184.—Lesions of Cortex in Man, Causing Elevations of Temperature.

Experiments by Ott show that an increased supply of oxygen is not necessary to a rise of temperature. A great increase of arterial tension can not elevate the temperature over 1.5° F., as has been shown by Ott and Scott.

The tuber cinereum is also connected with the *vasomotor apparatus.* In experiments to find vasotonic centers in the thalami I have located them in their anterior part. Later experiments have led to more exact data. After puncture of the tuber with a fine probe a gradual fall of arterial tension ensued. In about forty minutes it amounted to one-fourth the absolute pressure. This fall invariably ensued in six experiments; so that there seemed little doubt that *vasotonic centers* exist in the thalami.

Thermo-inhibitory Centers.—Eulenberg and Landois discovered about the cruciate sulcus a center whose ablation was followed by an increase of temperature. Prof. H. C. Wood has shown that the increase is due to augmented production of heat. I have also shown in the cat that at the juncture of the suprasylvian and postsylvian fissures is another center whose removal is followed by an increase of temperature. This has been confirmed by White.

The increased heat-production after injury to the Sylvian and cruciate centers, the fall to normal, and the subsequent rise in some cases indicate that there is a conflict between these centers and those that lie beneath in an effort to gain the mastery. This state of things is seen in the temperature of patients afflicted with fever.

Puncture, like fever poison, excites the thermogenic centers. Antipyretics act as sedatives to them and so reduce their excitability.

Albumoses, peptones, skatol, guanine, and neurin have been shown by Ott to produce fever.

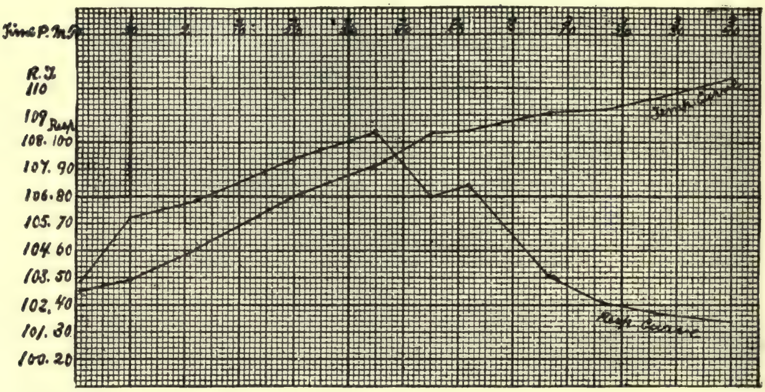

Fig. 185.—Curves of Temperature and Respiration when Cortex is Removed and the Animal is Artificially Heated.

Dr. W. Hale White reports a case in which a bullet from a pistol caused an injury of the anterior extremity of the middle lobe of the right hemisphere and also the third frontal convolution, which was followed by a temperature of 104.4° F. in less than twelve hours after the accident.

Dr. Page also reported a case of depressed fracture of the skull which was about the posterior part of the temporo-sphenoidal lobe and which was followed by a temperature of 105° F. This temperature fell after trephining, and it did not rise again. Fig. 184 shows the position of these lesions in man, and they correspond roughly to the position of the cruciate and Sylvian centers in the cat.

THERMOLYTIC CENTERS.—These centers include the cooling apparatus of the body: the polypnœic, the sudorific ,and the vasomotor centers.

Polypnœa.—Professor Richet found that with the elevation of the body-heat of an animal its respirations suddenly increased to 350 or 400 per minute. This form of respiration he termed polypnœa. It was found that the animal did not do this from want of oxygen. An animal pants to cool himself, while a man perspires for the same purpose. The rôle of polypnœa is exclusively to regulate the temperature of the body.

I have made numerous experiments to determine the exact seat of the polypnœic center. To establish a center three things are necessary: (1) that its abolition causes the phenomena to disappear, (2) that irritation—mechanical, chemical, or electrical—causes the phenomena to be present, and (3) that the part of the nervous system exhibiting these peculiarities be circumscribed in extent. After numerous observations and experiments it was found that pressure upon the tuber cinereum with a pledget of cotton, or even slight puncture, increased the normal respirations to the point of polypnœa. Complete puncture in a normal animal was followed by a rise to 106° F. within two hours, even though the animal was bound down and had been subjected to considerable shock.

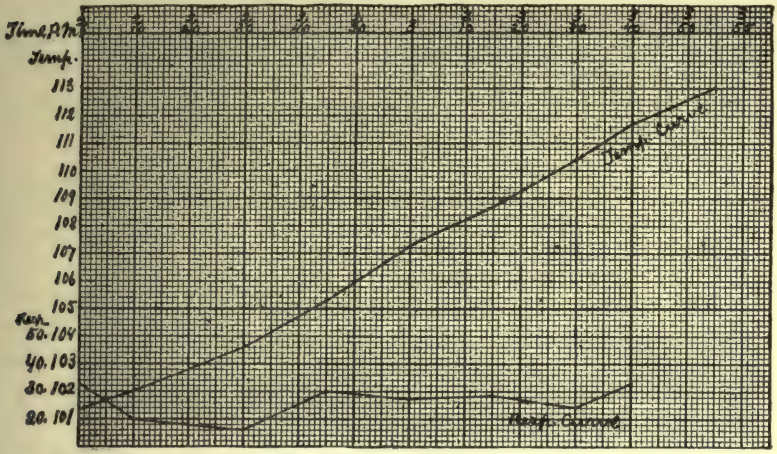

Fig. 186.—Curve of Temperature and Respiration when the Tuber Cinereum is Destroyed and the Animal is Artificially Heated.

If now the animal whose tuber is punctured be heated, there will result *no* polypnœa, even though a temperature of 107° F. be reached. I am convinced that the *tuber cinereum is a center of polyp-*

nœa and thermotaxis. When heat is thrown on the body the polypnœic center telegraphs the respiratory center to work more rapidly to throw off more moisture by the expired air.

The afferent nerves of the thermotaxic apparatus are probably those nerves in the skin administering to the "hot" and "cold" spots.

Regulation of Loss of Heat, or Thermolysis.—Heat is lost by an animal in various ways. It may be by direct radiation and conduction from the skin, by the extraction of heat during the process of evaporating perspiration, by warming the respired air, and by the discharge of urine and fæces.

Skin Radiation and Conduction.—The skin is the main means of escape of the bodily heat. Nearly three-fourths of the heat which escapes from the economy does so through the skin as a means.

A marked difference between the temperature of the skin and that of the surrounding atmosphere constitutes a prime factor in radiation. When the enveloping medium is very cold radiation from the skin's surface is very rapid.

The cutaneous circulation has considerable to do with the dissipation of heat. The caliber of the peripheral vessels is governed by the vasomotor system, which is itself under the guidance of the central nervous system.

External heat reflexly causes dilatation of the cutaneous vessels, so that at such times the skin becomes red and engorged. It contains more fluids and thus is a better conductor of heat. More blood being at the body surface allows of greater and more rapid loss through radiation.

External cold reflexly causes a contraction of the peripheral vessels; so that their lumina are narrowed. In consequence there is less blood circulating in the skin, which appears pale and contains less fluid; so that the radiation of heat is markedly hindered.

By reason of nervous stimulation the sweat-glands are at times made to functionate very freely; whereupon the skin's surface becomes bathed in a sensible perspiration. For the conversion of this moisture into vapor heat is necessary. It is by the abstraction of this heat from the underlying tissues that the body owes much of its loss when its parts are hyperpyrexial. One pound of water in evaporating takes up 1047 B. H. U. daily.

The covering of the body by clothing during various seasons of the year contributes much to the proper regulation of loss of heat, so that the mean temperature may be maintained fairly constant.

Fever.—The process of fever is one of absorbing interest dur-

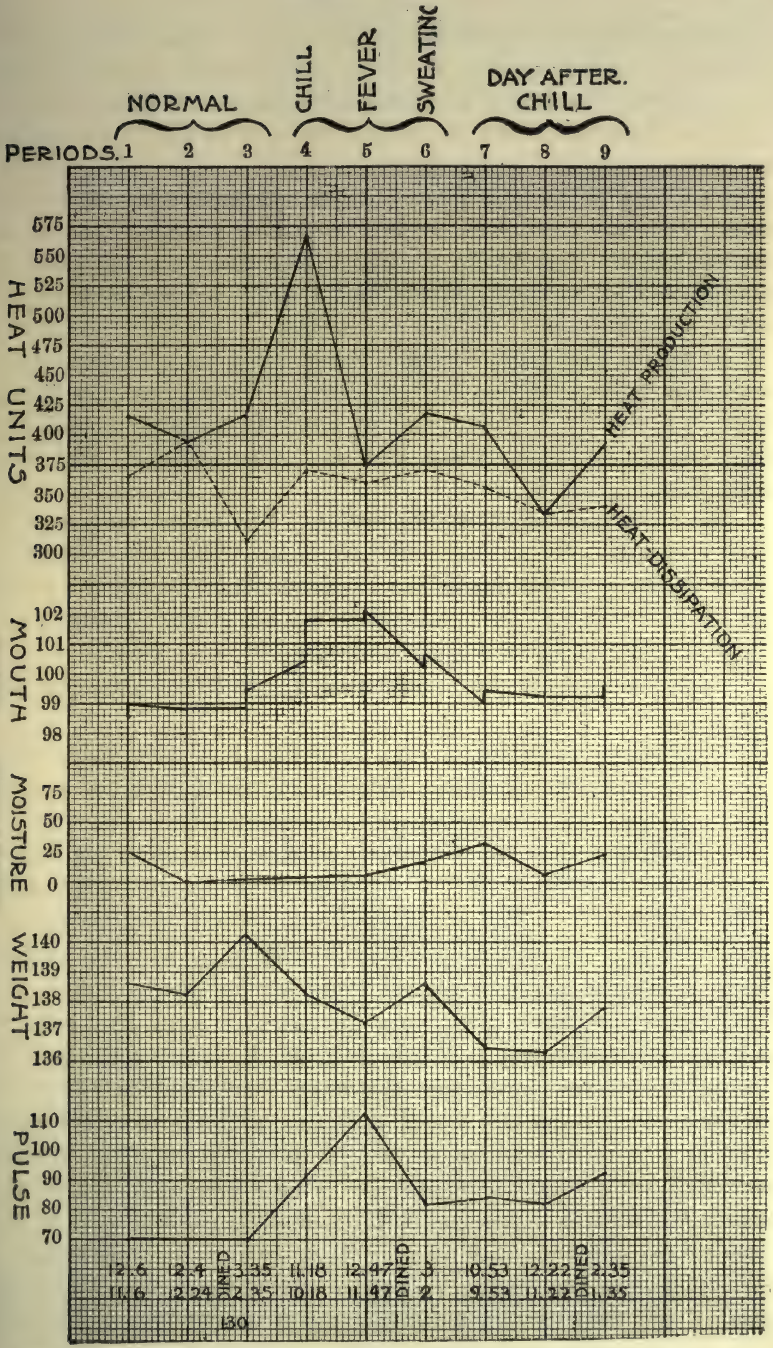

Fig. 187.—Heat Production and Heat Dissipation in Man during a Paroxysm of Malarial Fever—a Great Increase of Heat Production.

ing every period of a physician's life. The constant level of temperature in man is accounted for by two theories: One that it is due to changes in heat-production; the other, held by a minority, that it is kept so by changes in heat-dissipation under the varying conditions of external temperature.

In a case of fever generated by the malarial parasite I found with the human calorimeter an increased production of heat as the primary cause of the fever. In the case of fever generated by the subcutaneous injection of putrid blood I found a fever caused by an increased production of heat in the animal.

As a rule, it is true that fever is set up by an increase of heat-production beyond that of heat-dissipation. But when this is once established the fever continues, not from an excessive production, but from an altered relation between heat-production and heat-dissipation.

That the basal thermogenic centers, the corpus striatum and tuber cinereum, play a prominent part in the production of fever is proved by the fact that putrid blood and betatetrahydronaphthylamin both produce a rise of temperature. They are powerless after a section behind the tuber cinereum to elevate the temperature.

Antipyrin reduces the temperature by an action upon the corpora striata.

Experiments in my laboratory by Dr. W. S. Carter proved that whilst the temperature of the body has a rhythm, there was no rhythm in either heat-production or heat-dissipation.

All recent researches go to show that fever is not a fire that is continuously kept up by an excessive oxidation of the constituents of the human body. For instance, if the amount of water flowing into a vessel partly filled with water is equal to 2, and the amount going out is equal to 2, the level of the water will be the same. But if the amount of water going into the vessel is equal to 3 and the amount going out equal to 2, the level of the water will rise. If, however, the amount going into the vessel should suddenly fall to 1 and the amount going out should do the same, the level of the water would be nearly the same as before. If, now, you substitute for the amount of water going in the amount of heat produced, and for the water going out the amount of heat dissipated, and the level of the water as the height of temperature, it is easy to see how a diminished production and dissipation of heat due to want of food and the waste of the body by the fever process, may still keep up a high fever, although both are diminished below what is generated and dissipated in a state of health.

The physico-chemical cause of death in fever by hyperpyrexia is due to a coagulation of cell-globulin. If heated long enough, a temperature of 42° C. will coagulate it.

Postmortem Temperature.—Usually after death the body cools gradually, depending upon the temperature of the external atmosphere and the body-surface. The body of a child or emaciated subject cools more rapidly than does that of a well-developed and well-nourished adult body.

A *temporary increase* of postmortem temperature is due to the change of myosinogen into myosin and to those series of *chemical changes* immediately succeeding death.

When death has occurred from tetanus, acute rheumatism, typhoid, small-pox, cholera, or injuries to the brain, there is noted a marked postmortem rise in temperature.

CHAPTER XI.

THE MUSCLES.

Covering up the bones and attached to their surfaces at certain definite places is the soft, red, fleshy portion of the body: the *muscular substance.* This consists of not one homogeneous environing mass, but of a great number of distinct fleshy masses, called *muscles.* These are of various forms and sizes; number about four hundred; and are, for the most part, arranged in pairs. It is mainly to the shape and disposition of these muscles that the body owes the regularity of its contour.

It is by the power of these skeletal muscles that the animal is able to move about, procure means of sustenance, care for its young, etc.; but it must be borne in mind that muscles—not so powerful as are the skeletal muscles, but muscles, nevertheless—are contained within the viscera and blood-vessel walls. These muscles have very important functions to perform in aiding the processes of metabolism: that balance which when disturbed produces, not health, but disease.

Any animal *motion* means *muscle.* Muscular tissue is empowered with *contractility;* that is, an ability to shorten itself when acted upon by any stimulus. By its shortening it produces movement to parts to which one or both of its ends are attached. The resultant motions may be the very common ones of walking, running, various manual employment, etc., or the peristaltic movements of stomach and intestines, or the variations in the sizes of the lumen of the blood-vessels. Any animal movement should at once recall to the mind of the student that it is the resultant of some muscular contractility produced by the influence of a stimulus to it, whether that be nervous, electrical, mechanical, or thermal.

Muscular tissue consists of fibers bound together into those distinct organs already mentioned as muscles, and in this condition is known as the meat of animals.

In the fine anatomy of the muscles I have followed the writings of Professor Shaefer, as they appear in Quain's "Anatomy," of which this is an abstract.

Varieties.—When seen under the microscope, these fibers are found to be *cross-striped,* or *striated;* as many of them are under the control of the will, they are usually spoken of as being *voluntary.*

In the coats of the blood-vessels and in the hollow viscera is another variety of muscular fibers, often making a distinct layer or layers to these organs. In this kind the fibers do not have the cross-striped appearance, but are plain, or *unstriped.* Nearly all of these are not under the control of the will, and are, hence, *involuntary.* It must here be noted, however, that the muscle of the heart—which, as everyone knows, is an involuntary muscle—is exceptional to this class of muscle in that its fibers are very plainly cross-striped. Nevertheless, it presents differences from the striped fibers of skeletal muscles; so that it has become customary with very many authors to class it under the separate title *cardiac muscular tissue.*

The muscular fibers of the skeleton are generally collected into distinct organs of various sizes and shapes which have at each end a tendon by which they are attached to the skeleton.

The fibers of the muscles are collected together into bundles, called *fasciculi.* In the fasciculi the fibers are parallel, so that the fasciculi wind from one tendinous end to the other, except in a few muscles like the rectus abdominis. In this instance the body of the muscle is interrupted by interposed tendinous tissue. The fasciculi themselves do not mingle with one another and, for the most part, run parallel, although in many cases they converge to their tendinous endings.

The covering of the entire muscle is termed the *epimysium,* and is a connective-tissue envelope. The covering of areolar tissue which insheathes the fasciculi of the muscle is spoken of as the *perimysium.* The latter, a septum from the epimysium, furnishes to each fasciculus a special covering as well as furnishing it with blood-vessels and nerves. Within each compartment lie a number of muscle-fibers which are usually parallel to one another and held together by a very delicate reticular connective tissue. This areolar network is called the *endomysium,* but does not make a continuous covering and so cannot be said to form sheaths for them. Each fiber of the muscle, however, has a tubular sheath, but this sheath is *not* composed of the areolar tissue just mentioned. The special function of the areolar tissue seems to be to connect the fasciculi and fibers, and to support and conduct the blood-vessels and nerves in their ramifications between the various parts.

Fasciculi in form are prismatic, so that a transverse section shows an angular outline. The thickness of a fasciculus, as well as the number of fibers of which it is composed, varies. The texture of a muscle, whether coarse or fine, depends upon the large or small fasciculi contained within it; thus, the glutei are coarse, the muscles of the eye fine.

The length of the fasciculi is not always the same as the length of the muscle; this characteristic depends upon the arrangement of the tendons to which the muscle is attached. When the tendons are attached to the ends of a long muscle, as the sartorius, the fasciculi run from one end of the muscle to the other and so are of considerable length. However, a long muscle may be made up of a series of short fasciculi attached obliquely to one another by beveled ends. Short fasciculi thus attached, as in the rectus muscle of the thigh, have stronger action than where they run the extent of the muscle.

FIBERS.—The form of the muscle-fibers is cylindrical or prismatic with rounded angles. Their diameter varies very considerably, even in each muscle, although a certain standard is found to exist in every muscle. The largest human fibers average one-tenth of an inch in diameter, and from that size to one two-hundred-and-fiftieth of an inch fibers may be found. Between the size of the muscle and that of its fibers there is no constant relation.

The *length* of the muscular fibers does not generally exceed one and one-half inches. Thus, in a long fasciculus, the fibers do not reach its whole length, but end in a rounded or tapering end invested with sarcolemma and cohering with neighboring fibers. There is, as a rule, no anastomosis or division of the fibers of a muscle, except in the tongue of a frog, where they branch beneath the mucous membrane to which they are attached. The same thing has been observed in the tongue of man.

SARCOLEMMA.—The sarcolemma is a tubular sheath inclosing the soft substance of the muscle. It is an elastic, transparent, homogeneous membrane; it is rather tough and can remain intact even though the muscle be ruptured. Upon its inner side are found nuclei which, however, belong to the muscle rather than to the inclosing membrane.

Structure.—With a low magnifying power, the muscle presents clear pellucid fibers which are cross-striped with bands alternately dark and light. That this striation is not on the surface alone, but extends throughout the substance of the muscle, is readily demonstrated by altering the focus of the microscope. The stripes do not occur on the sarcolemma, but throughout the sarcous substance inclosed by the former.

The breadth of the bands is about $^1/_{17000}$ inch, so that eight or nine dark bands may be counted in $^1/_{1000}$ inch. While this is the

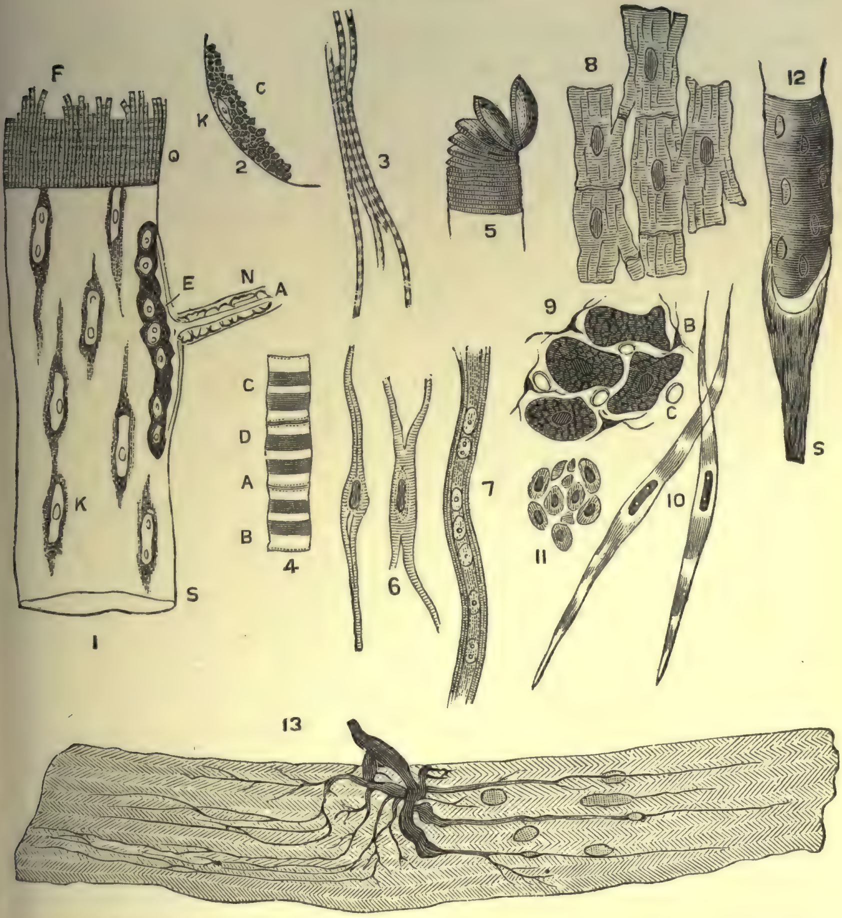

Fig. 188.—Histology of Muscular Tissue. (Ellenberger.)

1. Diagram of part of a striped muscular fiber. *S*, Sarcolemma. *Q*, Transverse stripes. *F*, Fibrillæ. *K*, Muscle nuclei. *N*, Nerve-fibers entering it with *A*, its axis cylinder, and Kühnes motorial end-plate, *E*, seen in profile.

2. Transverse section of part of a muscular fiber, showing Cohnheim's areas, *C*.

3. Isolated muscular fibrillæ.

4. Part of an insect's muscle, greatly magnified. *A*, Krause-Amici's line limiting the muscular cases. *B*, The doubly refractive substance. *C*, Hensen's disc. *D*, Singly refractive substance.

5. Fibers cleaving transversely into discs.

6. Muscular fiber from the heart of a frog.

7. Development of a striped muscle from a human fœtus at the third month.

8, 9. Muscular fibers of the heart. *C*, Capillaries. *B*, Connective tissue corpuscles.

10. Smooth muscular fibers.

11. Transverse section of smooth muscular fibers.

12. Muscular fibers with tendon.

13. Interfibrillary muscular nerves.

common breadth in human muscle, yet they are much narrower in different parts; so that there may be twice as many bands existing in the space just mentioned. This striation is found in all muscles attached to the skeleton, in the heart, pharynx, upper œsophagus, diaphragm, urethral sphincter, external anal sphincter, as well as in the muscles of the middle ear.

When a muscle is deeply focused, the appearance of the striæ is somewhat altered; a finely dotted line is seen to pass across the middle of each light band. This is supposed to represent *Krause's membrane* stretching across the fiber and attached to the surface of the sarcolemma. However, there is reason to believe that the appearance of a dotted line in this position in the fresh fiber is due to the peculiar optical condition of the tissue.

A fine, clear line is sometimes seen in the middle of each dark band, and is known as the *line*, or *disc of Hensen.*

Since there seems to be such variance as to muscle-structure and so many different names are met with in text-books, it might be well to call the student's attention to the fact that Dobie's line, Amici's line, and Krause's membrane are terms used to describe the same condition. They designate the dark line bisecting the white band. Hensen's band occurs in the dark bands.

In addition to the cross-striping, the fiber of the muscle has *longitudinal striation.* When a muscle has been very carefully teased with fine needles after having been previously hardened in spirits, an interesting result follows. The muscle-fibers break up into fine, longitudinal elements of a rounded or angular section which run from end to end of the fiber. These have been very aptly termed *muscle-columns, or sarcostyles.*

Each sarcostyle appears to consist of a row of elongated prismatic particles with clear intervals. These particles are termed *sarcous elements.* The sarcostyles in some muscles are striated longitudinally. This appearance has led some authors to believe that they are composed of still finer elements, or fibrils.

Under some conditions, the fibers show a tendency to cleave across in a direction parallel to the bands, and even to break up into transverse plates, or discs. The latter are made up by the lateral cohesion of the sarcous elements of adjacent sarcostyles. To the formation of such discs, therefore, every sarcostyle furnishes a particle, which coheres with its neighbors on each side, and this with perfect regularity.

Sarcoplasm is the intercolumnar substance by which the sarcostyles are united into the muscle-fibers. It is the protoplasm of the muscle-corpuscles, and forms a fine network throughout the whole muscular fiber.

From an examination of the aforementioned facts, Bowman was induced to believe that the division of the fiber into fibrils, or sarcostyles, was merely a phenomenon of the same kind as the separation into discs, only a more common occurrence.

COHNHEIM'S AREAS.—If a transverse section be made of a muscular fiber, or the surface of a separated disc be examined with a strong objective, there appear in the field small polygonal areas separated by fine lines. In acid preparations they give the appearance of a network. These areas represent sections of the muscle-columns, and are usually designated as *Cohnheim's areas.* The line between them represents the sarcoplasm, or intercolumnar substance.

When a muscle-fiber placed in fresh serum is examined, fine, longitudinal lines are seen running through the cross-striping. If, now, a weak acid is added to swell the muscular substance and render it more transparent, these lines can be traced from end to end of the fiber. By careful management of the microscope, it is found that these lines are really the optical section of the planes of separation between the sarcostyles; that is to say, the optical effect of the sarcoplasm, or intercolumnar substance. The sarcoplasm, in transverse section, presents the aspect of network; in longitudinal optical section it has the appearance of fine, parallel lines. The student can very readily imagine how these effects can be produced by the presence of a small amount of interstitial substance lying between closely packed prismatic columns.

In most muscular fibers the sarcoplasm exhibits a peculiarity of arrangement which has a very characteristic influence upon the optical appearance of the fiber. In a longitudinal view of fresh muscle, the lines representing intercolumnar sarcoplasm present at regular intervals along their course rather marked enlargements. These enlargements lie in the bright cross-striæ, either in their middle or near their junction with the dim cross-stripes. These sarcoplasm nodules have the appearance of dots upon fine longitudinal lines which run through the muscle; in the more extended fibers these dots are in double rows. In less extended parts they are thicker and blend together in the middle of the bright striæ.

Structure of the Wing-muscles of Insects.—The study of these muscles has furnished the key to the comprehension of the intimate structure of muscle. As to their structure, the wing-fibers are in complete agreement with ordinary muscles.

Wing-fibers occur in large bundles of muscle-columns or sarcostyles imbedded in considerable amount of granular sarcoplasm, while the whole of the structure is inclosed within a sarcolemma. The nuclei are scattered here and there. The quantity of sarcoplasm in wing-muscle is relatively far greater than in the ordinary muscle.

When wing-muscle has been carefully teased into muscle-columns, or sarcostyles, it is found that they contract while the sarcoplasm is quiescent. The muscle-columns can then be very carefully studied, when they show, like other muscles, the alternate bright and dark cross-striping. Each bright stria is bisected by a line which is the optical section of a transverse membrane: the membrane of Krause. These membranes divide the fibers into a series of segments, called *sarcomeres.*

In a muscle hardened by spirits each *sarcomere* is seen to contain: (1) in its middle, a strongly refracting, disclike sarcous element; (2) at either end (next the membrane of Krause) a clear interval occupied by hyaline substance. With strong lenses the sarcous elements can be made out to be composed of a sarcous substance which stains with logwood; it is pierced by short, tubular canals which extend from the clear interval as far as the middle of the disc. It is these canals which give to the sarcous element its longitudinal striping.

If, for any reason, the sarcostyle becomes extended, the sarcous elements tend to separate into two parts with an interval between them; *vice versa*, if the muscle be contracted or retracted the sarcous elements tend to encroach upon the clear intervals. At the same time the sarcous elements become swollen, so that the sarcomeres are bulged out at their middle and contracted at their ends.

Changes in Contraction.—When these muscles contract, the sarcous elements become bulged out and shortened, while the fluid of the clear interval becomes relatively diminished in amount. The ends of the sarcomeres are thereby contracted opposite the membrane of Krause, so that the sarcostyles become moniliform. This alteration in the shape of the sarcostyle necessarily affects the sarcoplasm which lies in their interstices. It must become squeezed out of the parts which are opposite the bulgings of the sarcostyles and into those parts which are opposite their constrictions. In other words, the sarcoplasm must accumulate in greater quantity opposite the clear bands and the membranes of Krause, and must necessarily diminish in amount opposite the sarcous elements.

In the living muscle this change in the position of the sarcoplasm during contraction can be observed; the muscle-columns tend to cause the contracted parts to appear dark, the bulged parts bright, in comparison.

Appearance of Muscle under Polarized Light.—Brücke was the first to point out that the fiber is not composed entirely of a double refracting, or anisotropous, substance. In addition there is a certain amount of *singly* refracting, or isotropous, material. This investigator points out that there is a difference between the appearances presented by living muscle examined in its own plasma and those of dead and hardened muscle examined in glycerin. In living muscle nearly the entire fiber is doubly refracting, the isotropous substance occurring only as fine transverse lines or as rows of rhomboidal dots which are united to one another across the anisotropous substance by fine longitudinal lines. Sarcous element is anisotropic; sarcoplasm is isotropic.

Nuclei.—In muscles that are cross-striped are found a number of clear, oval nuclei. They are sometimes spoken of as *muscle-corpuscles.* In mammalian muscle they usually lie upon the inner surface of the sarcolemma. In the muscles of the frog and reptiles the nuclei lie in the substance of the fiber surrounded by a small amount of protoplasm. When the nuclei lie immediately beneath the sarcolemma they are more or less flattened. Each nucleus contains one or two nucleoli. Mitotic figures, denoting division of the nuclei, have been observed. The nuclei are not very readily seen in fresh muscle, due to their being of the same refractive index as the sarcous substance. Only after they have undergone some spontaneous change or acetic acid has been added to the specimen can they be readily discerned.

In the rabbit and rays of fishes some of the voluntary muscles present differences from others, both as to appearance and mode of action. Thus, while most of the voluntary muscles are pale and contract forcibly when irritated, the soleus and semitendinosus show different characteristics. They are of a deeper color and respond with slow, prolonged contractions when stimulated. Thus, in these animals there are red and white muscles.

In other animals, this distinction of muscles is not found as regards a whole muscle, but may affect individual fibers. Thus, in the diaphragm many of the fibers have numerous nuclei imbedded within the protoplasm so as to form an almost continuous layer beneath the sarcolemma.

Relation to Tendons.—When a muscle terminates in a tendon, it is found that the muscular fibers either run in the same direction as the fibers of the tendon or join with the tendon at an acute angle. According to Toldt, the delicate connective-tissue elements covering the several muscular fibers pass from the latter directly into the connective-tissue elements of the tendon. According to another author, the ends of the muscular fibers are believed to be fastened to the smooth tendons by means of a special cement. However, it is probable that the areolar tissue which lies between the tendon-fibers passes between the ends of the muscular fibers to be gradually lost in the interstitial connective-tissue.

Blood-vessels of Muscle.—The blood-vessels to the muscles are very numerous. The average muscle leads such an active life that its nourishment and repair material must be in proportionate relation. Unlike the organs, as the kidney and spleen, which usually are supplied by one artery and vein, muscles receive *several* branches from various arteries which pierce the muscle at different points along its course.

The artery and vein usually are in close proximity, being held in position by the connective tissue upon the *perimysium.* The capillaries lie between the muscle-fibers in the *endomysium,* but *outside* of the *sarcolemma.* Here the capillaries are small, and form a fine network with narrow, oblong meshes, which are stretched out in the direction of the fibers. The capillaries have both longitudinal and transverse vessels. The lymph that is destined to support the sarcous substance must pass through the sarcolemma to reach the same.

Muscle Nerve-supply.—The nerve-supply to muscles is both motor and sensory. Each *muscle-fiber* receives a motor nerve-fiber. The *trunk* of the motor nerve, as a rule, enters the muscle at its geometrical center (Schwalbe); thus, the point of entrance in a long, spindle-shaped muscle lies near its middle. At this "geometrical center" there is the point of least disturbance during contraction of the muscle. After the trunk of the nerve pierces the muscle it proceeds to divide dichotomously until there are just as many nerve-fibers as muscle-fibers. A nerve-fiber now enters each muscle-fiber, to do which, of course, it must pierce the sarcolemma. The point of entrance forms an eminence known as *Doyere's eminence,* or *motorial end-plate.* At this point the sheath of the nerve-fiber becomes continuous with the sarcolemma. The eminence itself consists of a mass of protoplasm (sarcoplasm) containing granules and nuclei. Beneath the sarcolemma the original nerve-fiber is broken up into a number of divisions, spoken of as nerve-endings. These are divisions of the axis-cylinder which are spread *over* the sarcous substance without piercing it. To this branched arrangement of the nerve-endings Kühne gave the name *motor spray.*

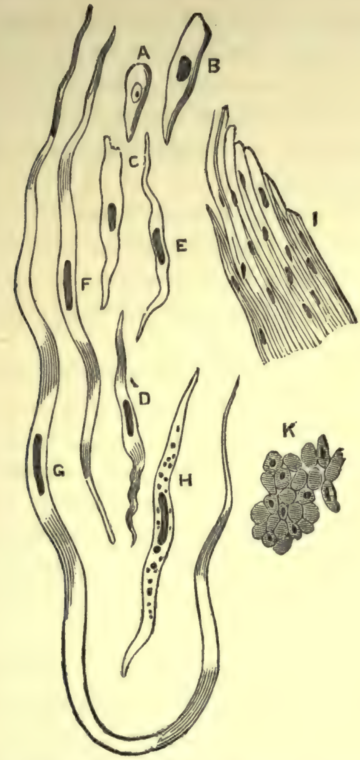

Fig. 189.—Unstriped Muscular Tissue. (Ellenberger.)

A and *B*, Fœtal cells. *C*, *H*, Fully formed fiber. *I*, Bundle of fibers. *K*, Cross-section of bundle of pale muscular fibers.

The nerve-endings are thus confined to very small areas on the muscle-fibers which have been termed by the same author *fields of innervation.* As a rule, each muscle-fiber has but one such area; it is the exception to find more than one, but as many as eight have been found in very long fibers.

Sensory fibers are also found in muscles, for it is through their presence that we obtain muscle sensibility. They seem to be distributed upon the outer surface of the sarcolemma, where there is formed a plexus. This plexus winds round the muscle-fiber.

Cardiac Muscle.—Some mention has previously been made concerning cardiac muscle, so that at this point only its most striking peculiarities will be mentioned, and that cursorily. (*a*) It is a striped muscle. However, its striations are not nearly so distinctly marked as are those of voluntary muscle. Occasionally it is noticed to be marked longitudinally. (*b*) Cardiac muscle-fibers possess no sarcolemma. (*c*) Its fibers branch and anastomose. (*d*) The nucleus is placed in the center of each cell. One author says that cardiac muscle stands, physiologically, midway between striped and unstriped muscle. When stimulated, its contractions occur slowly, but last for a considerable length of time.

Nonstriped Muscle.—These muscles are made up of a number of contractile fiber-cells, of an elongated, fusiform shape, usually pointed at the end. These fiber-cells may be readily demonstrated by placing the tissue in a strong alkaline solution or in a solution of strong nitric acid.

Upon transverse section they are generally prismatic, but sometimes are more flattened. Their muscle-substance is doubly refracting. Each cell has a nucleus which is either elongated or oval. It may contain one or more nucleoli. The nucleus is brought into view by means of dilute acetic acid or staining reagents.

The involuntary fiber-cells have a delicate sheath, which, like the sarcolemma of voluntary muscle-fiber, is very apt to become wrinkled when the fiber is contracted. By reason of this an indistinctly striated appearance may be produced.

While fiber-cells do occur singly, yet it is more common for them to be found in groups. Thus, muscular sheets, or bundles, are produced which may cross one another and interlace, being held in position by enveloping connective tissue. The individual cells are united by the presence of a very delicate *cement.*

The average length of the fiber-cells ranges from $^1/_{100}$ to $^1/_{200}$ of an inch; those forming the middle coat of the arteries are shorter, those in the intestinal tract and pregnant uterus are considerably longer.

Where Found.—The unstriped muscular tissue is more generally distributed within the body than one would suppose. It is found in the lower part of the œsophagus, in the stomach, small and large intestines; in arteries, veins, and lymphatics; in the ureters, bladder, and urethra; in the internal female generative organs, etc.

Blood-supply.—The blood-supply to unstriped muscle is very free, but not nearly so liberal as that to voluntary muscle. The *nerve-supply* is from the *sympathetic system,* and comprises both medullated and nonmedullated fibers. The fibers form a main plexus, lying in the connective tissue of the perimysium. From this plexus of fibers there come off numerous *fibrils,* which traverse the fiber and nucleus.

Irritability of Muscle.—Contractility, elasticity, tonicity, and irritability are terms used to designate various properties of muscles.

Thus, *contractility* is the property the muscle possesses of shortening and of giving a contraction when it is excited.

Elasticity is the general property, common to muscles and many other bodies, of stretching under the influence of a weight and of then returning, more or less perfectly, to the first shape.

Tonicity is the state midway between extreme contraction and relaxation. It is a condition depending upon the central nervous system.

In addition, muscle possesses a property that is common to all live tissues and which is of fundamental importance in general physiology. It is *irritability.* By irritability is meant that property of a living element to act according to its nature under the stimulus of an excitant.

Paralyses have been observed which have lasted for several months or even several years and, although the nerves were absolutely unexcitable, yet the muscles had retained their irritability. This may be readily demonstrated in cases of paralysis of the seventh pair of nerves.

The independence of muscle irritability is formally demonstrated by experiment in which the known action of the drug, curare, upon muscles is taken advantage of. A watery extract of this drug, when injected into the blood of an animal or introduced beneath its skin, acts chiefly upon the *motor nerve-endings.* It does not, however, affect muscular contractility. Curare is an agent which separates the muscle-element from the nerve-element by a physiological dissection much superior to the coarse anatomical dissections which we could make.

When a few milligrams of this drug are injected into the dorsal lymph-sac of a frog, the poison is absorbed within a few minutes. The animal soon ceases to support itself, but lies in any position in which it may be placed by the experimenter. It is paralyzed, producing neither voluntary nor reflex movements. Now, should the brain be destroyed, the skin removed, and the sciatic nerve stimulated by electricity, no movements of the muscles of the limb follow. On the other hand, should the stimulus be applied directly to the muscles, they immediately *contract*. Therefore the muscle is irritable by itself.

By this it would seem to be clearly demonstrated that irritability belongs to the muscle, and does not depend upon the nerve-fibers mingled with those of the muscle.

In addition to this classical experiment there may be mentioned several other facts which go to corroborate what has been mentioned concerning irritability:—

1. The chemical excitants of the muscle are not the same as the chemical excitants of the nerves. Thus, glycerine excites the nerve, but has no effect upon the muscle.

2. Isolated muscle-fibers have been seen which, according to microscopical examination, contained no nervous elements and which, notwithstanding, were contractile.

3. If the decreasing progress of irritability be followed after death, in the muscle as well as in the nerve, it will be found that the nerve dies long before the muscle. When the nerves have lost all irritability, the muscle is still alive, and can contract under the influence of excitations directly applied to its tissue. It is at that very moment when the nerves have lost all excitability that the muscle is at its maximum of irritability.

INFLUENCE OF BLOOD UPON IRRITABILITY.—It has been demonstrated by experiment upon the frog that when the artery of a member is ligated the muscle contraction is less high and less strong than if the artery had been left intact.

Stenon's experiment of ligating the abdominal aorta of a dog is worthy of mention. In twenty to thirty minutes after the ligation the dog seems paraplegic. He is unable to stand upon his hind limbs. Reflex and voluntary movements are completely lost; *muscle irritability, however, persists for nearly three hours.*

When the ligature is removed movement does not return to the limbs at once, but within a very short time the dog is able to stand upon his four feet.

Stimuli.—Those extreme forces which bring into play the irritability of the muscle are simply various forms of energy. To them the name *stimuli* has been applied. By their action the muscle is thrown into a state of excitement whereby the chemical energy of the muscle is transformed into heat and work. These muscle excitants, or stimuli, are of five varieties: (*a*) *nervous*, (*b*) *electrical*, (*c*) *thermal*, (*d*) *mechanical*, and (*e*) *chemical*.

Nervous Stimuli.—The most important of all the excitatory forces of the muscle is innervation. In the normal state there is scarcely any other than this to produce muscle contraction. Our muscles, as well as those of all other animals, contract because the motor nerve transmits to them the spontaneous or reflex excitation of the nervous centers. The nerve impulses average about ten per second. The stimulus is exactly proportioned to the effect which must be obtained.

Electrical Stimuli.—Electricity is employed in preference to any other external agent to bring into play the irritability of muscle.

Thermal Stimuli.—Thermic excitations also provoke muscular movements. The stomach and intestines are viscera whose muscles are very readily excited by heat and cold. They contract very energetically when very cold drinks are taken and their temperature is suddenly modified. On the contrary, striated muscles hardly react to thermic excitants. If heat or cold be applied gradually, there is not produced any muscle contraction. Excitants act only when they are applied suddenly.

Mechanical Stimuli.—Mechanical excitants that are capable of producing muscular contraction are rather common. Thus, the surgeon, while performing an operation, notices slight fibrillary tremblings following each stroke of his scalpel.

Chemical Stimuli.—It can be stated as a rule that all the substances which are fatal to the life of the muscle are excitants of the muscle. On this ground, distilled water is an excitant, for when it is injected into the arterial system of a frog its muscles show fibrillary twitchings. Not only does the water excite the muscle, but it also kills rapidly.

Chemical Constitution of Muscle-tissue.—The chemical study of muscle is one of the most difficult of physiological chemistry. There are in the muscle proteid matters very like one another and which can be distinguished only by superficial characters. This renders results far from being satisfactory or reliable.

Besides, it is necessary, in order to know chemical reactions of muscles, to study only living muscle. But from previous study it will be recalled that even the weakest chemical actions produce very decided changes in the muscles, with consequent alteration of its chemical functions.

Then, too, muscle-fiber is mingled with many other tissues, arteries, veins, nerves, connective tissues, etc.; the separation of the muscular fiber from its enveloping media is almost impossible completely to effect.

Reaction.—Living muscle is alkaline; however, after extreme activity and after death its reaction is found to be acid. This is due to the development of sarcolactic acid. The postmortem change in muscular constitution is due to spontaneous coagulation of a proteid within the muscle-fibers.

Constituents of Muscle.—Proteids.—Most abundant, myosinogen (pseudoglobulin), paramyosinogen (euglobulin) of muscle existing as one-fourth in amount of myosinogen.

Coloring Matter.—Myohæmatin.

Ferment.—Myosin ferment, and another ferment in muscle which, with the activitor of the pancreatic juice, destroys sugar.

Extractives.—(1) Non-nitrogenous Extractives:—

1. Glycogen.
2. Dextrin and sugars.
3. Lactic acid.
4. Inosite.
5. Fat.

(2) Nitrogenous Extractives:—

1. Creatin.
2. Creatinin.
3. Xanthin.
4. Hypoxanthin.
5. Uric acid.
6. Urea.
7. Carnine.
8. Carnic acid.
9. Inosinic acid.
0. Taurine.

Carbohydrates of Muscle.—(1) *Glycogen.* (2) *Lactic Acid.* (*a*) The optically inactive acid, ordinary lactic acid of fermentations, as in milk; small quantity in muscle. (*b*) Dextro-rotary lactic acid. This is paralactic or sarcolactic acid, the chief lactic acid of muscle.

The bulk of authority tends to prove that sarcolactic acid mainly comes from proteid.

Urea.—A small quantity in muscle (0.07 to 0.02 per cent.). It is supposed that most of the creatin is broken up into ammonia before it leaves the muscle.

Myosin.—Myosin is formed from *myosinogen, myosin ferment,* and *calcium salts.*

Syntonin.—When a solution of myosin is heated it is altered in such a manner that it can no longer be dissolved in NaCl as before.

If it be treated with dilute HCl, it becomes altered in still another manner, and produces an important substance which is called *syntonin.*

If syntonin in HCl solution have pepsin added to it, the syntonin is transformed into *peptone.*

Muscle-serum.—In the coagulation of blood two principal components are noted: the clot and the serum floating upon the clot. Also, after coagulation of the muscular juice, myosin and serum must be distinguished.

The muscle-serum which floats upon the surface of the myosin contains several substances.

The amount of proteid matters contained in the muscular tissues is very variable. It is usually stated that in 100 parts, by weight, of muscle, there are 20 parts of proteid matters.

EXTRACTIVES.—Creatinin is derived from creatin by dehydration. The amount of creatinin in muscle is small, being but 0.2 per cent.

Hypoxanthin and xanthin occur to the extent of about 0.02 per cent.

Halliburton found a *myosin-ferment.* Its presence would seem to explain the coagulation of myosin.

GLYCOGEN.—Among the nonnitrogenized substances must first be classed the sugars and their analogues. *Glycogen* is the principal muscle-starch. The glycogen in the muscles was discovered by Claude Bernard while looking for the glycogen in the liver of the fœtus and newborn. He found in the muscles of the embryo quantities of glycogen that were relatively enormous. Glycogen exists in all of the muscles.

The more active the state of a muscle, the less glycogen it contains. Therefore, much of it is found in those muscles which contract but little.

Muscle extract and pancreatic activator when mixed together rapidly destroy sugar in the blood, probably by the formation of a ferment. Either extract alone is powerless to break up glucose. These two extracts resemble the action of enterokinase upon trypsinogen.

INOSITE.—It is a sort of crystallizable body that is unfermentable. That is, it does not ferment to form alcohol, but *lactic acid.* It is found in the vegetable kingdom also, where it is usually extracted from peas or beans. It is identical with the inosite of muscle. It is not a sugar, but belongs to the aromatic series.

MINERAL SUBSTANCES.—Alkaline phosphates predominate. In 100 parts of ash there are about 90 parts of phosphates. The metals found in muscle are potassium, sodium, and calcium; there is also a small quantity of magnesium and iron. Phosphoric acid exists in muscle as inorganic phosphates, phosphorus of phosphocarnic acid, and phosphorus of inosinic acid. Carnic acid is identical with antipeptone. When a muscle works it increases the phosphates in the urine. The gases found in muscle are carbonic-acid gas and oxygen.

Adipocere is a waxy substance which replaces muscular tissue if bodies be buried in damp soil. It consists principally of a soap made of calcium with palmitic and stearic acids.

Rigor Mortis.—During *rigor mortis* the muscles become rigid, hard, inextensible, shortened and swollen, as though in a state of contraction. After death, *rigor mortis* is a constant phenomenon. The muscles to first become rigid are the masseter, temporal, and internal pterygoid. Then it seizes the muscles of the trunk and neck, then the arms and the legs. Tetanus and rigors appear in the same muscles and extend to others in the same way.

In *rigor mortis* the thumb is in the palm of the hand and covered with the other fingers, showing that the flexor muscles overcome their antagonistic muscles, the extensors. The jaws are contracted, the eyes are widely open, the head and neck are drawn backward, the abdomen is depressed, the extremities are half flexed, and the feet are extended.

CAUSE OF RIGER MORTIS.—It is due to the myosinogen becoming myosin by the action of the myosin ferment with calcium salts. During *rigor mortis* the muscles become acid, due to sarcolactic acid and acid phosphates, the muscle becomes cloudy, and gives off heat and carbonic acid. After some time *rigor mortis* passes off and the body becomes relaxed. After fatigue the *rigor mortis* ensues rapidly after death, lasts but a short time, followed by putrefaction. It is well known that butchers do not kill animals tired by a long walk, but wait for a rest of some days.

In man it is generally four hours after death that cadaveric rigidity becomes complete. As a rule, it may be said that rigidity begins two hours after death, reaching its maximum two hours later.

A particular kind of *rigor mortis* has been observed by military surgeons. Soldiers while in full activity have been struck by projectiles and have been seen to become stiff instantaneously. It is a sort of *rigor mortis* which seizes all of the muscles of the body immediately after death.

Influence of Temperature.—Animals which have died in *heated chambers* become rigid very quickly and the rigidity disappears as quickly.

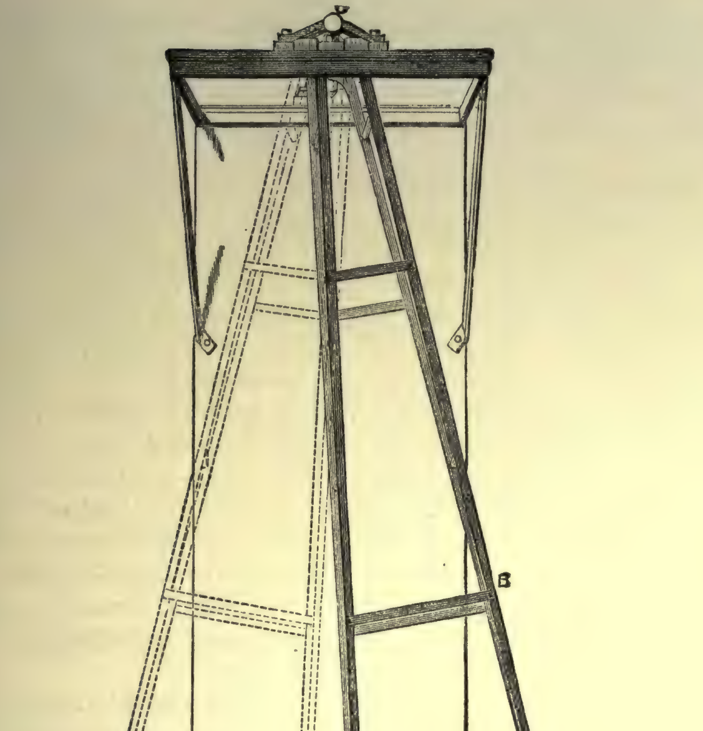

Fig. 190.—The Pendulum Myograph. (Foster.)

A, Smoked glass plate, swings on the "seconds" pendulum, *B*, by means of carefully adjusted bearings at *C*. The contrivances by which the glass plate can be moved and replaced at pleasure are not shown. A second glass plate, so arranged that the first glass plate may be moved up and down without altering

Cold, which retards chemical phenomena, retards the appearance of cadaveric rigidity and prolongs it enormously.

Influence of Fatigue.—The influence of prolonged labor of the muscle upon the premature appearance of rigidity is an indisputable fact.

Muscular Labor and Urea Excretion.—With the ordinary diet of fats, carbohydrates, and proteids, muscular labor greatly increases the output of carbon by the lungs in the shape of carbon dioxide, whilst the nitrogen excreted as urea is slightly, if at all, increased. In a fasting animal work increases the excretion of both the carbon and the nitrogen. The output of carbon is proportional to the work done, the nitrogen not being so closely proportional. Here the muscle procures its energy from the proteids, whilst the animal with an ordinary diet uses up mainly the carbohydrates and fats.

Hence, in muscular exertion the chief foods—proteids, fats, and carbohydrates—are metabolized in order to set free heat and work. In doing this the muscle prefers to break up the fats and carbohydrates rather than the proteids. Hence when muscle fulfills its two chief functions, to produce work and heat, it uses up the fats and carbohydrates and proteids, but the proteids are chiefly used to build up and repair the muscle-substance itself.

SARCOLACTIC ACID.—The production of sarcolactic acid is the more abundant as the muscle has been longer and more strongly excited.

Myograph.—The du Bois-Reymond induction coil is the one most commonly employed in physiological experiments. When it is

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the swing of the pendulum, is also omitted. Before commencing an experiment the pendulum is raised up (in the figure to the right) and is kept in that position by the tooth (*a*) catching on the spring-catch (*b*). On depressing the catch (*b*) the glass plate is set free, swings into the new position indicated by the dotted lines, and is held in that position by the tooth (*a'*) catching on the catch (*b'*). In the course of its swing the tooth (*a'*), coming into contact with the projecting steel rod (*c*), knocks it on one side into the position indicated by the dotted line (*c'*). The rod (*c*) is in electrical continuity with the wire (*x*) of the primary coil of an induction-machine. The screw (*d*) is similarly in electrical continuity with the wire (*y*) of the same primary coil. The screw (*d*) and the rod (*c*) are armed with platinum at the points at which they are in contact, and both are insulated by means of the ebonite block (*e*). As long as *c* and *d* are in contact the circuit of the primary coil to which *x* and *y* belong is closed. When in its swing the tooth (*a'*) knocks *c* away from *d*, at that instant the circuit is broken, and a "breaking" shock is sent through the electrodes connected with the secondary coil of the machine and so through the nerve. The lever (*l*), the end only of which is shown in the figure, is brought to bear on the glass plate, and when at rest describes a straight line, or more exactly an arc of a circle of large radius. The tuning-fork (*f*), the ends only of the two limbs of which are shown in the figure placed immediately below the lever, serves to mark the time.

necessary to use very rapid breaking of the current, some instrument must be employed for that purpose. The first instrument used in making myograms was that of Helmholtz.

Simple Contraction.—If a single induction shock be applied to a muscle there will result a simple muscular contraction; that is, the muscle will respond by a quick contraction, with return to its former relaxed condition. This contraction, when graphically shown, is termed a *simple muscle-curve:*

Muscle-curve, or Myogram.—If the muscle-curve of a single stimulus be analyzed, it will be seen to be composed of various elements, as follows: (1) *period of latent stimulation,* (2) *period of contraction,* and (3) *period of relaxation.*

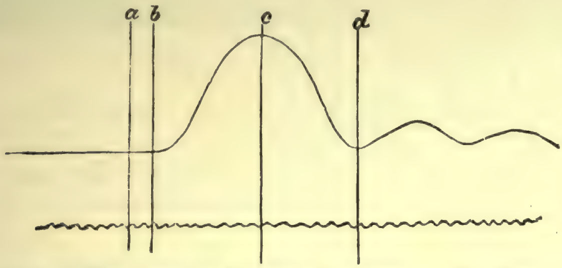


Fig. 191.—A Muscle-curve Obtained by Means of the Pendulum Myograph. (Foster.)

To be read from left to right.

a indicates the moment at which the induction-shock is sent into the nerve. *b*, The commencement; *c*, the maximum; and *d*, the close of the contraction. The two smaller curves succeeding the larger one are due to oscillations of the lever.

Below the muscle-curve is the curve drawn by a tuning-fork making 180 double vibrations a second, each complete curve therefore representing $^1/_{180}$ of a second. It will be observed that the plate of the myograph was traveling more rapidly toward the close than at the beginning of the contraction, as shown by the greater length of the vibration-curves.

Latent Period.—The significance of this term is that the muscle experimented with does *not* respond at the precise moment when the stimulus is applied to it. The response comes later—about $^1/_{100}$ of a second. During the latent period there is no *apparent* change occurring within the muscle. The latent period may be *modified* by increased stimulus and heat, when it becomes shortened; fatigue and cold lengthen the time. The latent period of unstriped muscle may be as long as one or two seconds.

Contraction Period.—The muscle-curve comprises two periods: that of the ascent and that of the descent of the muscle. The ascent of the curve represents the contraction of the muscle until it has reached its maximum. The rate of contraction is at first a trifle slow, then more rapid and more slow a second time. The extent is $^{4}/_{100}$ of a second.

Relaxation Period.—After the muscle has contracted to its maximum, it begins to relax—at first slowly, then more quickly, and finally more slowly again. Its duration is $^{5}/_{100}$ of a second. It is shorter with a weak stimulus and longer with a strong stimulus.

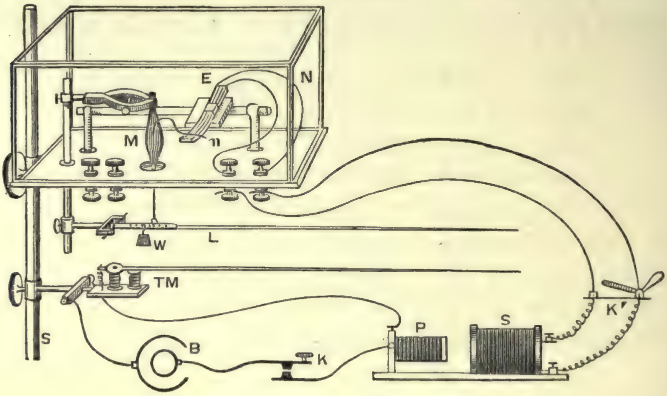


Fig. 192.—Arrangement of Apparatus in Conducting Experiments on Nerve and Muscle. (STIRLING.)

B, Galvanic battery. *K*, Electric key in primary circuit. *P*, Primary coil of induction machine. *S*, Secondary coil of induction apparatus, from which the current is conducted when the key (*K'*) is open to the electrode (*E*) on which rests the nerve (*n*). The muscle (*M*) is supported by a clamp under a glass shade, its tendon being connected by a thread with a lever (*L*) writing on the smoked surface of a revolving drum. The time-marker (*TM*) is included in the primary circuit so that when the current passes through *P* by closing the key (*K*) it also traverses the electromagnet of the time-marker and causes a record of the instant of stimulation to be made on the surface of the drum. *S*, Stand supporting moist chamber. *W*, Weight by which muscle is stretched and which is lifted in the contraction of the muscle.

In the myograph we use a light lever and a weight as near its axis as possible to record the contraction. Here the tension of the muscle in its contraction and relaxation remains nearly the same. This contraction is called an isotonic contraction. The isometric contraction is produced when the muscle pulls against a spring. Here the muscle undergoes slight change in length and the energy of change of form is transformed into tension and stored in the spring. An examination of isometric and isotonic curves proves that a muscle which has shortened to a given length will be making a far greater pull when its effort to shorten has been resisted than when it has reached the same during a contraction without resistance, which is an isotonic contraction.

Curve of Fatigue.—When a muscle has become fatigued and its myogram studied, at first the contractions improve for a short time. This is shown by the successive contractions being higher. Afterward the latent period increases, the curve becomes less high, while the contraction becomes *slower* and lasts longer.

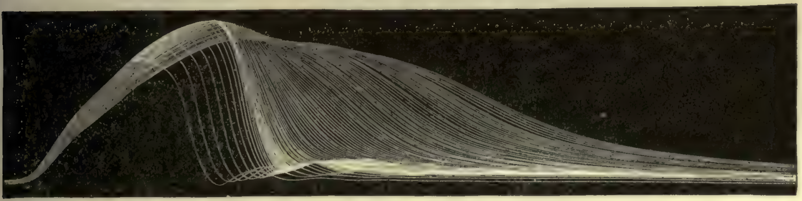


Fig. 193.—Fatigue-curves of Frog's Muscle. (Waller.)

Veratrine and adrenalin greatly prolong the stage of relaxation in a muscle.

Staircase Contractions.—When electrical stimuli of equal strength are let into a muscle at regular intervals and the contractions registered, it is seen that at first each curve exceeds its predecessor in height. It shows that the muscle is benefited within certain limits by contraction, and its excitability increased for a new stimulus, just as we can do better muscular work when we have warmed up our muscles. Bowditch first noticed the staircase contraction in cardiac muscle.

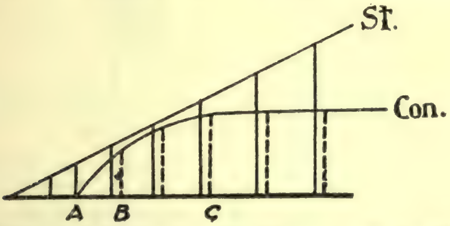


Fig. 194.—Influence of Increasing the Strength of the Stimulus upon the Contraction of Skeletal Muscle.

St, The stimulus. *Con*, The resulting contraction. *A*, A subminimal stimulus. *B*, The minimum adequate stimulus. *C*, The optimum stimulus. (Paton.)

Composition of Muscle Before and After Contraction.—Experiments show that constant chemical metabolism is going on in a muscle at rest. It is constantly taking in oxygen, glucose, and perhaps fats and proteids, and giving off carbonic acid. When the muscle becomes active and does work, then the chemical changes become more active.

The chief differences between resting and acting muscle are: (1) the acting muscle forms more CO_2; (2) more oxygen is consumed; (3) sarcolactic acid is formed; (4) glycogen is made use of; (5) the substances soluble in water diminish in amount, while those soluble in alcohol increase.

CHANGES IN THE VOLUME OF THE MUSCLE DURING CONTRACTION.—Muscular contraction can be defined by its apparent effects: a shortening of the muscle. By experiment it has been shown that the muscle on contracting simply shifts its muscular units when it shortens, for the volume of the muscle remains the same.

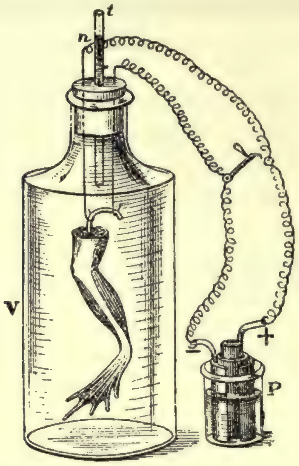


Fig. 195.—An Experiment to Show that a Contracting Muscle does not Change its Volume. (HEDON.)

***V*, Vessel filled with water containing the frog's foot, the nerve upon two electrodes. *t*, Capillary tube in which the level of the water is observed. *P*, Battery.**

Muscle-wave.—When a muscle is placed beneath two levers some distance apart, and one end of the muscle is stimulated, then a wave of muscular contraction runs through it. The distance between the points at which the two curves begin to rise from the abscissa gives the rate of wave-movement.

The continuity of the muscle-fiber is the reason the wave is propagated. The fibers stimulated are set into activity and the evolution of energy in them stimulates the neighboring fibers and the contraction passes along the muscle.

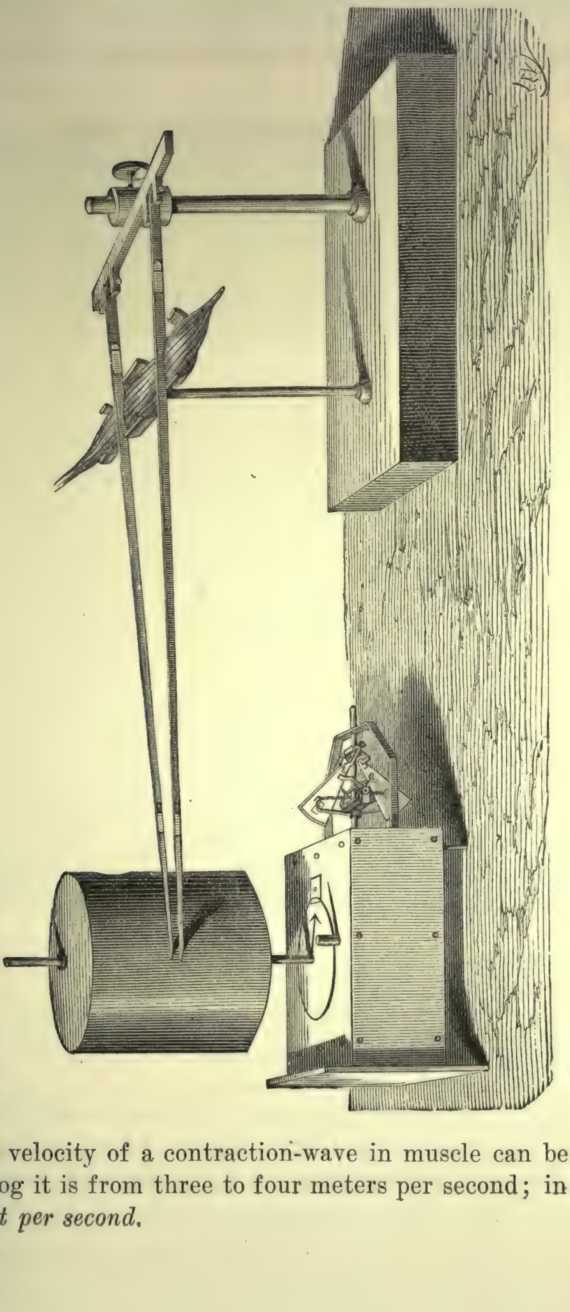


Fig. 196.—Apparatus for Measuring the Velocity of the Wave of Muscular Contractions. (Marey.)

The velocity of a contraction-wave in muscle can be measured; in the frog it is from three to four meters per second; in *man, about forty feet per second.*

The Effects of Two Successive Stimuli.—Let the student imagine two successive momentary stimuli applied successively to a muscle. The stimuli may be either *maximal* or *submaximal;* that is, either the greatest possible contraction the muscle is able to accomplish or only a medium contraction from the applied stimulus.

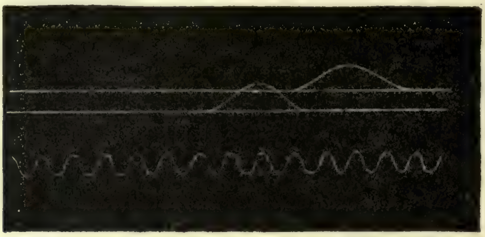


Fig. 197.—Rate of Conduction of the Contraction Process along a Muscle as shown by the Difference in the time of Thickening of the two Extremities. (MAREY, HOWELL.)

The tuning-fork waves record $^1/_{100}$ of a second.

If each of the two stimuli be *maximal*, the effects produced will vary according to the *time* of application of the two excitants. Thus, (1) if the second stimulus be applied after the relaxation following the effect of the first stimulus, then the myogram shows two maximal contractions; (2) if the second stimulus follow the first with such rapidity that the two occur during the latent period of the muscle-curve, then the recording instrument shows but *one* maximal contraction.

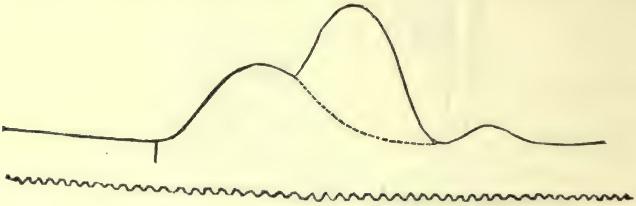


Fig. 198.—Tracing of a Double Muscle-curve. (FOSTER.)

To be read from left to right.

While the muscle was engaged in the first contraction (whose complete course, had nothing intervened, is indicated by the dotted line), a second induction shock was thrown in at such time that the second contraction began just as the first was beginning to decline. The second curve is seen to start from the first as does the first from the base line.

If the two stimuli be *nonmaximal,* the effects of the two separate stimuli will be superimposed; that is, there will be a *summation* of the contractions. This summation occurs regardless of the time of application of the stimuli.

Summation of Stimuli.—As the second stimulation was just seen to add its curve to the first, so does the third add itself to the second, the fourth to the third, etc. If the excitations occur with a rhythm that is not too rapid, the various shocks are nearly equal, as shown by the myogram, but yet they do not mingle. These isolated shocks are seen when the rhythm does not exceed six per second.

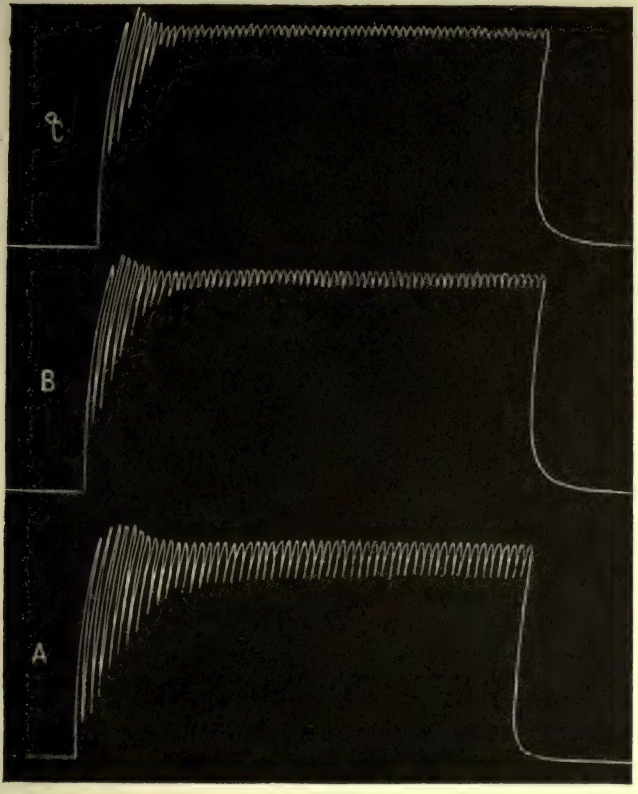


Fig. 199.—Progress in Fusion of Contraction. (Laulanié.)
***A* 6, *B* 7, *C* 8, per second.**

If, now, these same excitations be repeated with a frequency of twenty per second, isolated shocks will not be seen. Each stimulus, lasting but $^1/_{20}$ of a second, does not allow the muscle completely to relax; thus, the second contraction encroaches upon the first, the third upon the second, etc. From the rapid succession of the stimuli, the muscle remains in a condition of continued vibratory contraction. That is, in a state of *tetanus*.

Complete Tetanus.—If the excitation rhythm be more frequent,—say, fifty of them per second,—there will no longer be any trace of the primitive shocks. The ascent of the muscle-curve will be abrupt and decided; the contraction due to the first shock will not be followed by any relaxation. There will be no oscillation recorded upon the myogram. The upper straight line due to the complete contraction of the muscle is called the *plateau*. When the muscle is in this condition the tetanus is said to be perfect or complete.

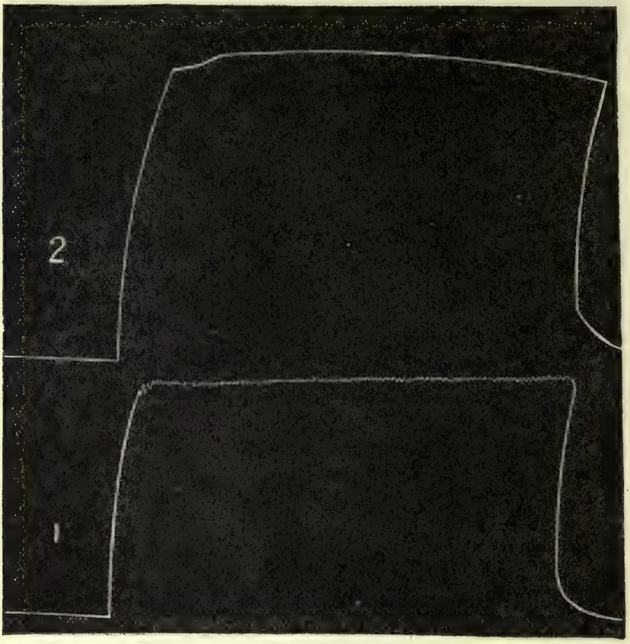


Fig. 200.—1. Imperfect Tetanus, 15 Contractions per second. 2. Perfect Tetanus. (Laulanié.)

The tetanus is spoken of as *incomplete* when there are still relaxations and vibrations which indicate the incomplete mingling of the shocks.

The *number* of *stimuli* that are required to produce tetanus may be very variable. Fifteen to twenty stimuli per second suffice to throw a frog's muscle into tetanus.

Duration of Tetanus.—A tetanized muscle cannot be kept contracted for a considerable length of time, even though the stimuli be kept constant. The muscle begins to elongate—at first somewhat quickly, but later more slowly. This change is produced by fatigue of the muscle.

Effect of Temperature on Muscle-curve.—Low temperature makes the contraction longer and lower; the latent period is longer, and the relaxation-curve is greatly not unlike that of a fatigued muscle. When the temperature is raised, the setting free of energy is more rapid; hence the time of contraction is shortened, especially the latent period and time of shortening of the muscle.

Strength of Stimulus.—If you apply a current just sufficient to cause a muscle to contract, and then increase the strength of the current, the muscular contraction will become more rapid and more complete. But the increase in contraction is not proportional to the increase in stimulus. As the stimulus is gradually increased, the increase in contraction becomes smaller and smaller. After a certain strength of stimulus is attained, a further increase of it does not cause any increment in the contraction of the muscle.

Amount of Load.—If a muscle is attached to a lever without any weight in the scale-pan, it is ascertained that light weights actually increase the height of the contraction, whilst heavier weights diminish it until a limit is reached, and when a sufficient weight is used the muscle no longer contracts.

Muscle-tonus.—This is a condition of a muscle more or less stretched, and is dependent upon the reflex activity of the central nervous system and a sufficient supply of blood to the muscle. If you cut a motor nerve going to a muscle, the muscle loses its tonus. If you divide all the posterior spinal roots, then the muscles also lose their tonus.

Muscle-sound.—Helmholtz said that 36 vibrations per second formed the average for the production of muscular tones. To-day this is considered an overtone, and the requisite number of necessary vibrations is placed at 19 per second.

First Heart-sound.—It is probable that the first sound of the heart is partly a muscle-sound. It is a dull sound, persisting when the thorax is taken away and the auriculo-ventricular valves are destroyed. The sound could not in such an instance be produced by the vibration of the valves.

Voluntary Contraction.—The *number* of single impulses sent to our muscles during voluntary movements are somewhat variable.

There are from 8 to 12 impulses for a slow movement and from 18 to 20 impulses per second for a rapid movement. Ten vibrations per second may be taken as the average.

Elasticity of the Muscle.—Of all the properties of muscle, elasticity is the one least well known, the one which is most difficult to explain and understand.

Physicists say that a body is *perfectly* elastic when, after having been removed from its first position, it returns exactly to the original position. Thus, an ivory ball is perfectly elastic; after it has been flattened by an external force it returns exactly to its original shape.

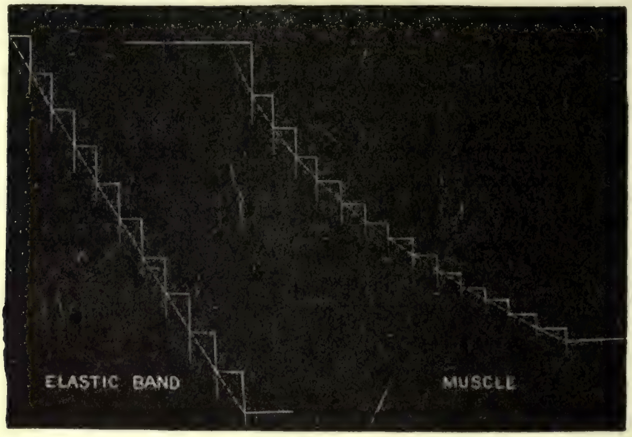


Fig. 201.—Extensibility of Elastic Band and Muscle. (Waller.)

If a piece of rubber is stretched by adding successive weights it is found that the series of elongations are nearly proportional to the weights. When the weights are successively removed it will be found that the elasticity of the rubber is nearly perfect. But if overweighted for a long time it does not return completely to its original length, and the elasticity disappears gradually. If now you take a frog's fresh muscle and successively load it, the extension of the muscle for each weight is not proportional to the weight used, but with each increase in weight the muscle stretches rather less, the greater the previous extension. On removing the weights the muscle shortens but it does not return to its original length. A contracted muscle is more extensible than a resting one. This prevents a rupture of the muscle in a sudden contraction.

Muscular elasticity preserves the tension of the muscle under all usual conditions. The muscles attached to the bones are in a state of elastic tension which is favorable to the action of the muscle, diminishing the danger of rupturing its fibers. The elasticity of muscle favors the economical expenditure of work by the muscle. A muscle is always taut, never in a state of relaxation, and it is then ready to efficiently exert mechanical force the moment it begins to contract. Heating to a certain extent increases and cooling decreases elasticity. The curve of muscle, when stretched by weights, is not a hyperbola, but one peculiar to muscle.

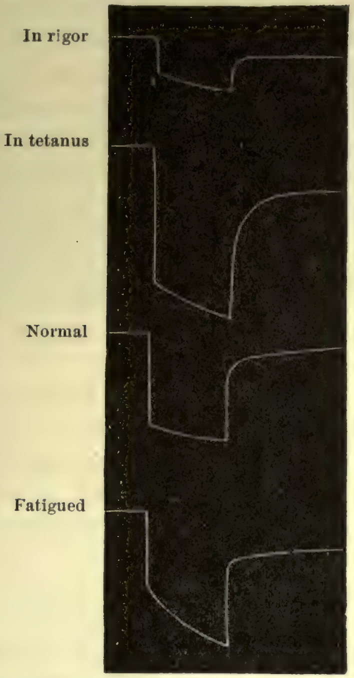


Fig. 202.—Extensibility of Muscle in Various States. (Waller.)
Tested by 50 grammes applied for short periods.

Muscular Work.—While treating of elasticity and its modification, tonicity, it might be well to give a brief discussion upon muscular work. The *amount of mechanical work* which a muscle performs equals the product of the weight lifted and the height to which the weight is lifted. Thus, the work = height × the weight.

When a muscle begins to contract, it is then that it lifts the greatest load; as the contraction continues, the muscle is capable of lifting less and less.

If the height be expressed in feet and the weight in pounds, then the work performed is measured in units of foot-pounds. Likewise, should the height be measured in meters and the weight in grams, then the work done is expressed in grammeters.

In studying the heights of contraction in a loaded muscle it is found that the heights of lift continuously diminish, but the actual work done by the muscle increases rapidly and then more slowly until it reaches its maximum with a load of 200 grams. After that point the work done slowly decreases and then more rapidly until it receives a load of 700 grams, when the muscle is unable to contract.

Dynamometer.—The common, clinical form of dynamometer is much used to determine the absolute force of certain muscles. The instrument is very useful to determine the difference in grip between the two hands in cases of paralysis. The patient grasps the instrument in his hand and squeezes upon it; the power exerted is registered in kilograms.

Muscles are Most Perfect Machines.—They take the best advantage of the fuel supplied to them and give in return a very high percentage of energy in the form of work. They, by legitimate exercise, increase in strength and power so that they progressively perform more work.

The steam engine, to which muscles are frequently compared, is inferior in every respect. The best-made steam engine shows as work only about 12 per cent. of the total energy supplied to it by the oxidation of the coal, while about 88 per cent. is transformed into heat. Muscle transforms 25 per cent. of its energy into work and 75 per cent. into heat to warm itself.

The proportion of work to heat is not a fixed one. If you gradually increase the stimulus, both work and heat increase; but the heat-production is increased more rapidly and reaches its maximum sooner. Heat-production decreases more rapidly than the amount of work produced, when the muscle is exhausted. When the muscle is loaded so it cannot contract, or an unweighted muscle is made to contract, no work is produced and all the energy is converted into heat.

Fatigue.—Fatigue is due to a chemical and physiological alteration of the muscles. It is characterized by a pain, more or less acute, localized in the muscles. The alterations in the muscles fatigued are due to an accumulation of toxic products of the metabolism of the muscle. Sarcolactic acid is one of these fatigue-products, and when applied to a muscle it causes a state of exhaustion. Whatever the fatigue-products may be, a muscle exhausted by a series of contractions is saturated with the so-called fatigue-products which have poisonous properties. The chemical theory of fatigue is proved by preparing a watery extract of muscles exhausted by a series of contractions, and injecting this into the circulation of a frog. Here it will cause the muscles to show fatigue in the same manner as when spontaneously caused. This fatigue of the muscles in the frog, caused by electric tetanus, can be removed and their irritability restored by the injection of solutions of sodium carbonate into the vein. This alkaline solution washes out the fatigue-products from the muscle. The circulation of blood normally washes away the toxic products of fatigue. Mosso has shown that the blood of a fatigued dog, when injected into the vein of another dog, caused all the symptoms of fatigue. In the fatigued muscles of the frog it is not necessary to have the blood wash away the products of fatigue, for it has been shown that the oxygen of the air in about half an hour can restore their irritability. If the muscle fatigued is placed in an atmosphere of hydrogen, no restoration of the muscle ensues. Oxidation is the restorative agent in fatigued muscles.

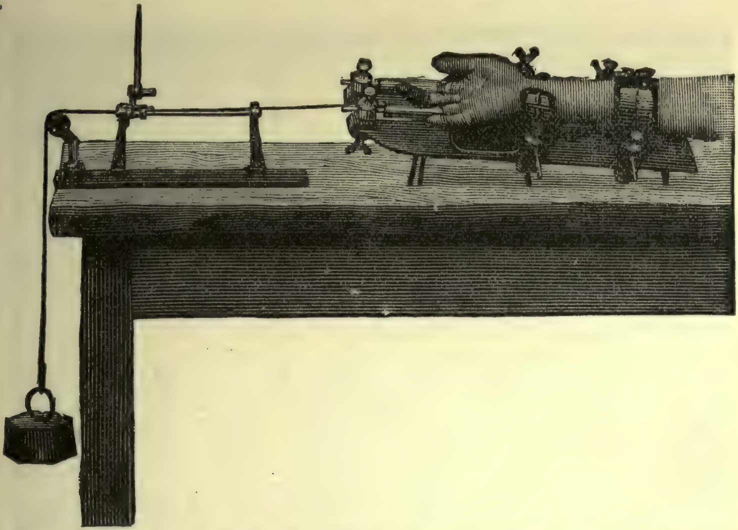


Fig. 203.—Mosso's Ergograph. (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

The Seat of the Fatigue.—When a nerve of a warm-blooded animal is curarized, artificial respiration being kept up, and electricity applied to the nerve, it causes no muscular response until the curare is excreted, when the muscle again contracts, showing that it is not the nerve or the muscle, but the motor end-plates, which are exhausted. Mosso has shown that if, with the ergograph, you lift a weight until the flexor muscle is exhausted, and then induction currents are applied to the nerves going to the muscle, the muscle will again lift the weight. This experiment shows that the fatigue-products generated in the muscle are carried by the circulation to the central nervous system and poison it. Hence the central nervous system is shown to be the chief seat of fatigue, and the motor nerve-endings the next.

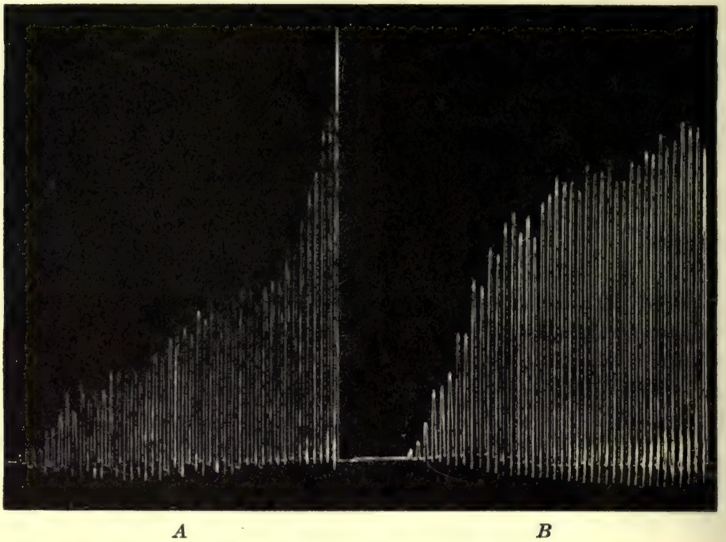


Fig. 204.—Ergographic Curves. (After Mosso.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Read from right to left.

Ergographic Curves.—The most salient feature seen in them is the rhythmical rise and fall, which is due to the central nervous system. During the first 180 contractions the height of the ergographic curve decreases, and then becomes nearly constant in the height, which is above 85 per cent. of the original contraction.

The curve indicates that during a series of contractions two processes are at work, the one using of material and the other an accumulation of fatigue-products in the first part of the curve. In the subsequent part of the curve, the fatigue-products are removed by the circulation, and the circulation supplies the materials to be used up.

Involuntary Muscle.—The same substances are found in plain muscle as in striated muscle, except that plain muscle contains six times more neucleoproteid than striped muscle. In its contraction the latent period is about a second, and the contraction lasts several seconds; it spreads as a wave from fiber to fiber. Its irritability is very dependent upon temperature; heat decreases its tonus, cold

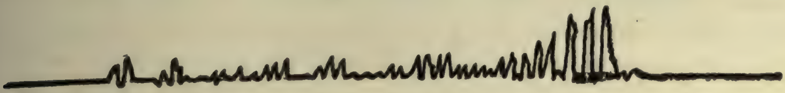


Fig. 205.—Ergographic Curve of a Case of Addison's Disease, Showing Rapid Exhaustion of Muscle. (LANGLOIS.)

Read from right.

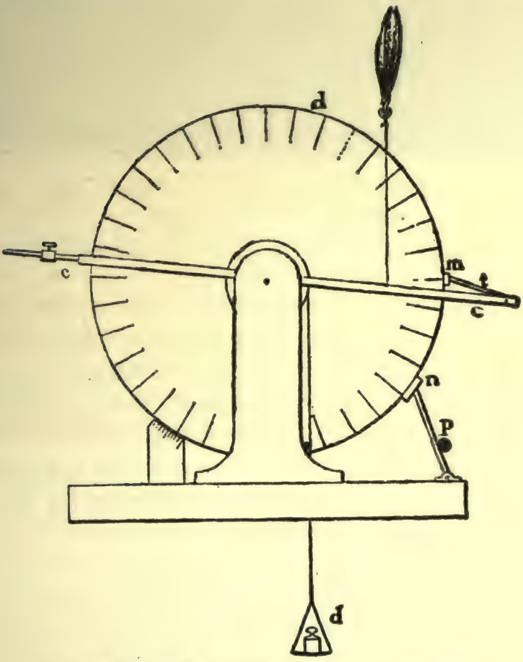


Fig. 206.—Fick's Work Adder. (LAULANIÉ.)

The wheel (*d*) bears upon its axle a counterpoised muscle lever (*c*), ending in a pawl (*m*), through which the wheel is caused to revolve when the lever is pulled upward by the attached muscle. A second pawl (*n*) prevents the wheel from turning back when the muscle relaxes. On the other side the axle of the wheel bears a pulley from which a weight (*d*) is suspended. The turning of the wheel winds the suspending cord upon the pulley and raises the weight (*d*). The muscle preparation should be the double adductor, suggested by Fick.

increases it. The stimuli to excite plain muscle are chemical, mechanical, and the opening and closing of a constant current. Organs containing unstriped muscle frequently exhibit involuntary rhythmical movements and a tendency to sustained tonic contraction. The force of the uterus in expelling the child and that of the bladder in expelling the urine show that plain muscle can do considerable work. Ordinarily, organs made up of nonstriated muscle are only faintly sensitive. These rhythmic contractions and relaxations, like the tonic contractions, are independent of the action of nerves, but are modified by it. Unstriped fiber does, like striped fiber, increase its height of contraction by increasing the strength of the stimulus. It can not be thrown into a state of tetanus by a series of stimuli. Rapid stimuli simply increase the force and rate of individual contractions. Smooth muscle, as a rule, contains nerve-plexuses and ganglion-cells. It has two kinds of functionally different nerves, motor and inhibitory. Both sets of nerves are connected with nerve-cells in their course, such as the plexuses of Auerbach and Meissner in the intestinal tract.

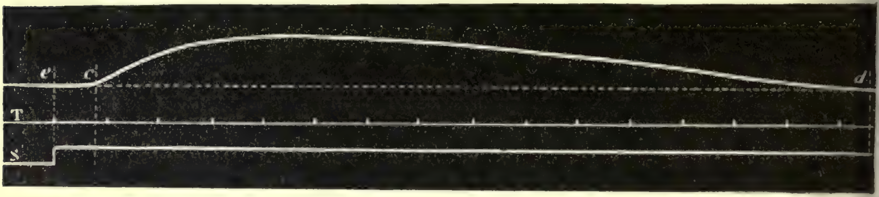


Fig. 207.—Curve of Contraction of the Unstriped Muscle of Müller in Dog. (Laulanié.)

The intervals on the line *T* are seconds.

CHAPTER XII.

VOICE AND SPEECH.

It has long been established that the sounds of the voice in man and mammalia are produced by the vibratory action of the vocal cords. It is usually the blast of *expired air*—under certain circumstances the inspiratory blast also—in its passage through the glottis that causes the tense vocal cords to vibrate. These cords vibrate according to the laws which regulate the vibration of stretched membranous cords. As a result of these vibrations sound is produced which, in man, is capable of being so modified as to constitute articulate speech.

Experiments upon living animals show that the vocal cords alone are the essential factors in the production of sound. For, so long as these remain untouched, although all other parts in the interior of the larynx are destroyed, the animal is still able to emit vocal sounds.

The existence of an opening in the larynx of a living animal, or of man, *above* the glottis in no way prevents the formation of vocal sounds; however, should such an opening occur in the trachea, it causes total loss of voice. By simply closing the opening sounds can be again produced. Such openings in man are usually met with as the result of accident, of suicidal attempts, or of operations performed upon the larynx or trachea for the relief of disease.

Production and Modification of Sounds.—Whenever a solid body surrounded by air is thrown into vibration the sensation of sound is carried to the ear. The vibrations must, however, be of certain strength and follow one another with certain rapidity. It is usually stated that if the vibrations be fewer than 32 or exceed 33,768 per second no effect is produced upon the nerve of hearing.

For the production of a musical sound the vibrations must succeed each other at regular intervals; if the vibrations occur at irregular intervals, only a noise results.

The *pitch* of a sound depends upon the number of vibrations within a given period of time. The pitch becomes higher in direct proportion to the rate of increase in the rapidity of the vibrations.

The *strength*, or *intensity*, of the sound depends upon the extent of the vibratory action of the sonorous body.

Tone, or *timbre*, is that peculiar character of a musical note whereby it can at once be distinguished from another note of exactly the same pitch and strength.

THE ORGAN OF VOICE.

The special organ of voice in man is that portion of the air-passages called the *larynx*. It is a sort of hollow chamber which extends from near the root of the tongue to the first ring of the trachea. It is placed in the middle line of the neck, where it forms a considerable projection, larger above than below.

Although the larynx is the proper organ of voice, yet the lungs and the moving parts of the thorax serve to propel the air through this organ. The cavities above it, including the pharynx, mouth, and nasal cavities, assist in modifying the vocal sounds. They are, therefore, adjunct organs of voice.

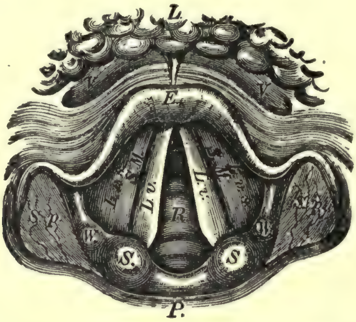


Fig. 208.—The Larynx as Seen with the Laryngoscope. (Landois.)

L., Tongue. *E.*, Epiglottis. *V.*, Vallecula. *R.*, Glottis. *L. v.*, True vocal cords. *S. M.*, Sinus Morgagni. *L. v. s.*, False vocal cords. *P.*, Position of pharynx. *S.*, Cartilage of Santorini. *W.*, Cartilage of Wrisberg. *S.p.*, Sinus pyriformis.

Anatomy of the Larynx.—The larynx consists of a cartilaginous skeleton which constitutes its walls; also vocal cords; muscles which move directly the cartilaginous pieces, and influence indirectly the tension of the cords; and finally, a mucous membrane which lines the internal cavity.

Cartilages.—The cartilages of the larynx are four in number: two unlike and two alike. One of the former is inferior and exists in the form of a signet-ring. It is the *cricoid*. This cartilage is continuous with the rings of the trachea. Its narrower portion is situated anteriorly; its wider portion is placed posteriorly. It articulates with the inferior cornua of the thyroid cartilage, forming the crico-thyroid articulation.

The other odd cartilage, the superior one, is called the *thyroid*. It is composed of two quadrilateral laminæ which meet in front at an angle. This projection is popularly known as Adam's apple. Each thyroid lamina terminates posteriorly in two horns: one superior, the other inferior.

The two cartilages which are alike are the *arytenoids.* Each one is in the form of a triangular pyramid, whose base is movably articulated at the back on the cricoid cartilage. The apex of each arytenoid cartilage has attached to it, in the shape of a movable point, a *cartilage of Santorini.*

The true vocal cords are attached to the anterior angles, or *vocal processes,* of the arytenoids; the crico-arytenoideus muscles are inserted into the external angles.

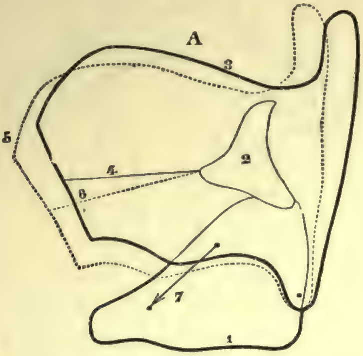


Fig. 209.—Action of the Muscles of the Larynx. (Beaunis.)

The dotted line indicates the new positions assumed by the thyroid cartilage in the action of the crico-thyroid muscle. 1, Cricoid cartilage. 2, Arytenoid cartilage. 3, Thyroid cartilage. 4, True vocal cord. 5, New position of the thyroid cartilage. 6, New position of vocal cords.

The *cartilages* of *Wrisberg* are found in the aryteno-epiglottic folds.

The *epiglottis* is attached to the inner surface of the anterior portion of the thyroid cartilage. It projects upward behind the base of the tongue. The epiglottis is attached to the tongue by the three *glosso-epiglottic folds.*

The *false vocal cords* are two folds of the laryngeal mucous membrane which pass from the anterior surfaces of the arytenoids to the thyroid cartilage. They are located above the true vocal cords.

The *true vocal cords* extend from the anterior angles of the bases of the arytenoids to the thyroid cartilage.

The *glottis* is the chink between the true vocal cords.

The *ventricle of the larynx* is the pouch between the true and false vocal cords.

The Muscles.—All of the laryngeal cartilages, joined together by ligaments, are moved by five pairs of muscles. The muscles of the larynx are divided into two groups: *intrinsic* and *extrinsic*. To the former group belong those muscles which are attached to the various cartilages. The latter collection comprises the musculature connecting the larynx to other parts like the hyoid bone.

Intrinsics.—Of these there are five pairs.

1. *The Crico-thyroid Muscles.*—These, which are in the anterior part of the larynx, originate in the front and sides of the cricoid cartilage below. Outwardly they are attached on each side to the lower edge of the thyroid cartilage. They become fixed by the action of the thyro-hyoid, sterno-thyroid, and laryngo-pharyngeal muscles.

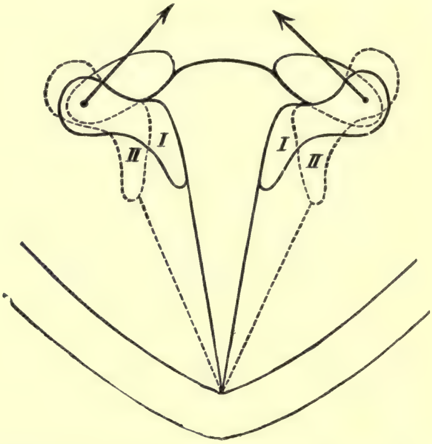


Fig. 210.—Schematic Horizontal Section of Larynx. (Landois.)

I, Position of horizontally divided arytenoid cartilages during respiration. From their anterior processes run the converging vocal cords. The arrows show the line of traction of the posterior crico-arytenoid muscles. *II*, *II*, Position of the arytenoid muscles as a result of this action.

Action.—They incline the cricoid cartilage upward and backward and so elongate and stretch the vocal cords, at the same time contracting the opening of the glottis.

2. *The Posterior Crico-arytenoid Muscles.*—These take their departure from the posterior surface of the shield of the cricoid cartilage. They then converge and are fastened to the base of the corresponding arytenoid cartilage.

Action.—In contracting they turn the anterior ends of the arytenoids outward, whereby they separate the vocal cords from each other and give a rhomboid form to the glottis. Thus it is materially widened.

3. *The Lateral Crico-arytenoids.*—These muscles are found upon the inner side of the cricoid. They are carried backward and upward and are fastened to the outside of the posterior ends of the bases of the arytenoid cartilages.

Action.—In contracting they rotate the arytenoid cartilage inward. They are antagonists of the posterior crico-arytenoid muscles; they narrow the vocal part of the glottis.

4. *The Thyro-arytenoid Muscles.*—This pair of muscles is inserted at the anterior end in the middle of the angle of the thyroid cartilage, and at the posterior end it is fastened to the inside of the anterior end of the base of the arytenoid cartilages. Each muscle of the pair runs its entire length parallel with the corresponding vocal cord.

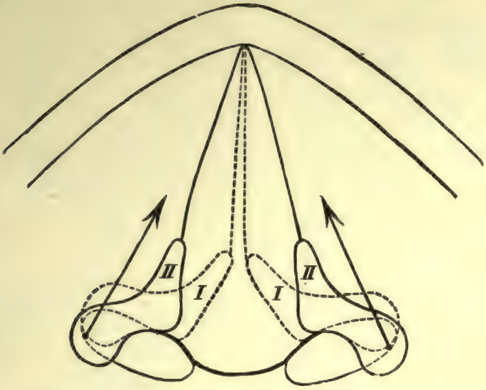


Fig. 211.—Schematic Closure of the Glottis by the Thyro-arytenoid Muscles. (LANDOIS.)

II, II, Position of the arytenoid cartilages during quiet respiration. The arrows indicate the direction of muscular traction. *I, I*, Position of the arytenoid cartilages after the muscles contract.

This muscle has two bundles: an internal and external bundle. The muscle draws the arytenoids toward the thyroid and relaxes the cords. By the internal bundle the anterior part of the vocal cord can be tightened while relaxing the posterior part. It is the muscle concerned in the production of the high notes in the singing voice.

5. *The arytenoid* constitutes an odd muscle. It extends posteriorly between the two arytenoid cartilages. The muscle is divided into two layers: one posterior, of oblique fibers disposed like an X; and one anterior, of transverse fibers.

Its action is, in contracting, to draw the arytenoid cartilages together so that the respiratory part of the glottis is closed. If the contraction be simultaneous with that of the lateral crico-arytenoid muscles, respiration is entirely interrupted.

THE EXTRINSIC MUSCLES are those of the anterior region of the neck; those in the suprahyoid as well as those in the subhyoid region. By the action of these muscles the entire larynx is moved upward and downward.

THE CAVITY of the larynx is lined with a mucous membrane. The mucous membrane is continuous with that of the trachea. It is covered with the prismatic or ciliated epithelium in all places except over the vocal cords and epiglottis. In these special areas it is stratified.

THE VOCAL CORDS comprise two sets, as was previously mentioned; the upper, false cords, composed of folds of mucous membrane, take no part in voice production; the lower, true cords, are composed of a mucous membrane with pavement epithelium, a lamina of elastic fibers, and the thyro-arytenoid muscle.

Opening the cavity of the pharynx and raising the epiglottis, the whole extent of the glottis is seen; that is, the slit left by the two superior cords. This has the shape of a much elongated triangle—apex in front, base at the back. The limited anterior part of the triangle is called the *vocal part* of the glottis; whereas the posterior part is called the *respiratory portion*. It does not participate in phonation, but only in the passage of air.

NERVE-SUPPLY.—The nerves which are distributed to the larynx come from the pneumogastric. The *superior laryngeal nerve* supplies the mucous membrane of the larynx and gives the external laryngeal branch to the crico-thyroid muscle. The inferior, or *recurrent*, laryngeal nerve supplies all of the muscles except the crico-thyroid. The ganglia which preside over the motor innervation of the larynx are seated in the floor of the fourth ventricle.

Laryngoscopy.—The laryngoscope is an instrument used to bring to view various parts of the pharynx, larynx, and trachea. It comprises a small mirror fastened to a long handle. The angle that the mirror makes with its handle is from 125 to 130 degrees.

CONDITION OF THE VOCAL CORDS.—By observations made with the laryngoscope it has been determined that, while in respiration the vocal cords are inclined *from* each other, and the glottis is wide open, in speaking or vocalization the cords are seen to approximate and *vibrate*. In ordinary quiet breathing there is a wide, triangular-shaped opening in the glottis. On the other hand, during the production of vocal sounds the triangular posterior opening is completely closed, while the anterior portion of the rima glottidis becomes a very fine fissure, or slit.

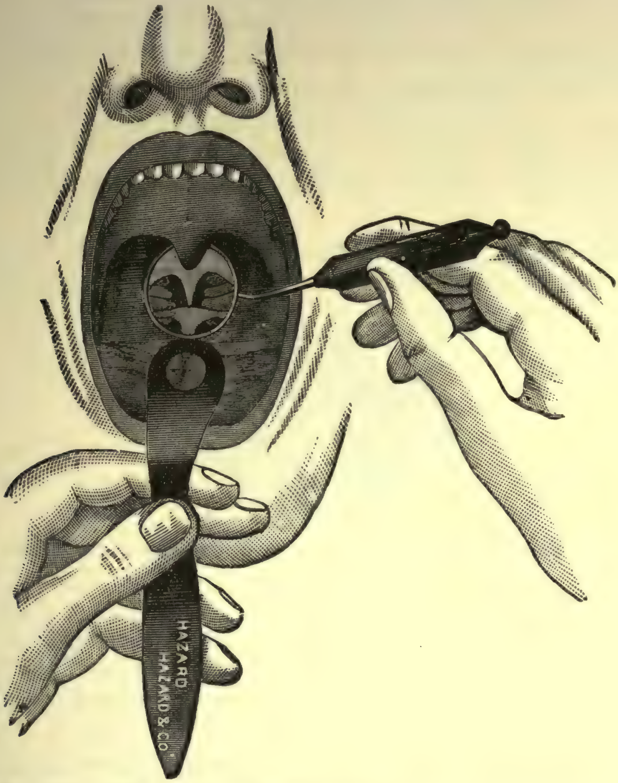


Fig. 212.—The Posterior Rhinoscopic Image. (Bosworth.)

VOICE.

It is the vibration of the edges of this fissure by the passage of air through it that produces sound: the voice. The air expelled from the lungs acquires a maximum of tension in the narrow tracheal tube, causing it to strike under the true vocal cords and put them into the proper vibrations. But the tone produced will not always be of the same caliber and height, since the expired air may find the vocal cords in different states, the result of muscular contractions.

The Height of the sound produced in the larynx depends upon the *number* of vibrations of the vocal cords during a given time.

The *number of vibrations would then depend upon the state of tension* and the *length* of the *cords themselves.* The greater the number of vibrations during a second, the higher will be the tone, and *vice versa.*

The range of the human voice, as regards *height,* is usually between 87 and 768 vibrations per second. Not all persons have such a range. Each type of voice includes about two octaves. When a man *speaks*—that is, when he uses the articulate voice—his voice does not exceed the height of a half-octave. When he sings, his vocal range is more extended.

The Intensity of sound depends upon the extent of the vibrations of the vocal cords, produced especially by the force of the current of air.

The *height* of the voice depends, to a considerable extent, upon different *lengths* of the vocal cords. The result is that in adult man the *bass, baritone,* and *tenor* voices are found, because of the greater length of the vocal cords in man. On the contrary, the *contralto, mezzosoprano,* and *soprano* voices belong to women and boys, for they have cords shorter in length.

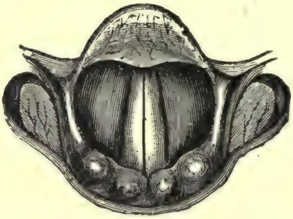


Fig. 213.—Position of Vocal Cords on Uttering a High Note. (Landois.)

Timbre of sound depends upon the nature of the vibrating body and of the other parts vibrating at the same time with it for the production of harmonious sounds.

Resonance.—The normal voice of man is sonorous; that is, it is composed of vibrations regular in extent and isochronous. Its resonance comes either from the *air-tube* or from the *resonators.* By the former is understood the trachea, bronchi, walls of the lungs, and thoracic case; by the latter, the ventricles, pharynx, mouth, and nasal cavities. The resonance within the thorax in an adult causes a *fremitus* of the thoracic wall. This is greatly increased in low sounds and diminishes until it disappears in high sounds.

Ordinarily, in speaking and singing, the air put in vibration in the larynx issues from the mouth while the nostrils are open. If they be closed, the air which is held there vibrates with the air issuing through the oral cavity and gives the voice a *nasal tone.*

The human voice can assume two different registers. The one is strong and sonorous and accompanied with vibrations of the thoracic wall (chest-voice). The other is weak, without resonance, and of higher pitch (head-voice, or *falsetto*).

Ventriloquy, which by practice can reach great perfection, consists only in the possibility of changing the register of the voice. The name derived its origin from the erroneous interpretation of it by the ancients. They claimed that the ventriloquists spoke from the stomach. The performer is able to conduct dialogues in which two persons appear to take part.

Speech.—If man had the faculty of making only *sounds* with the larynx, his vocal organ would not differ greatly from ordinary musical instruments. The voice in such a case would but serve to make others aware of his presence and to call them for the various wants of life, just as happens in animals and in the child itself when just born.

But man is endowed with an important means by which he can communicate to his fellows the state of his mind. It forms one of man's noblest characteristics, a distinctive one.

The infant at first expresses the state of his mind by cries accompanied by gestures. Then little by little it learns and tries to imitate those sounds which the parents always make corresponding to given objects and persons. It pronounces them without understanding their meaning. In later years it learns of the correspondence of given sounds to given objects and ideas.

Speech is articulate voice. It is an *ensemble* of sounds and noises harmonized by the will and co-ordinated by a particular cortico-motor nervous center. Its aim is to make known to the listener the present state of mind of the speaker as well as recollections of the past and tendencies toward the future.

VOWELS AND CONSONANTS.—Speech is composed of two elements, namely: *vowels* and *consonants.* The former consist of *sounds* generated in the larynx and slightly modified in the pharynx and mouth-cavity. The consonants result from *noises* variously produced by the obstacles encountered by the air in its passage through the pharynx and mouth-cavity. Vowels are produced in the larynx, pharynx, and mouth; consonants not in the larynx, but in the mouth.

The vowels are produced by the different form of the cavity of the pharynx and mouth during the expiration of air through them.

The principal change in form consists in the lengthening and shortening of the mouth. The vowels are *a, e, i, o,* and *u.*

The *consonants* consist of *sounds* emitted by the larynx, but which become *noises* by reason of obstacles they encounter. According to the obstructions met with, consonants are termed *gutterals* (*h, k, q*), *linguals* (*c, d, g, t, s, n, l, r*), and *labials* (*b, f, m, p, v*). The linguals are subdivided into *palatals* and *dentals.*

The very varied union of the vowels with the consonants constitutes *syllables;* union of the latter forms words.

Stammering is due to a continued spasmodic contraction of the diaphragm and to the muscles of the larynx not harmonizing the chink of the glottis.

Stuttering is due to a want of ability to form the proper sounds by the laryngeal muscles; the breathing and diaphragm are both normal.

Pathology.—Paralysis of the motor nerves of the larynx from the pressure of tumors, causes *aphonia,* or loss of voice. In aneurism of the aortic arch the left recurrent nerve may be paralyzed from pressure. The laryngeal nerves may be temporarily paralyzed by overexertion and hysteria.

If *one vocal cord* be paralyzed, the voice is not pure in tone, but falsettolike.

Hoarseness may be caused by mucus upon the vocal cords or by roughness or laxness of the cords. Disease of the pharynx or nasopharynx and uvula may, in a reflex manner, produce a change in the voice.

APHASIA.

Aphasia means a loss of power to produce or understand spoken or written speech.

Aphasia is a disorder of the speech, due to a lesion of the third left frontal convolution. There are four different kinds of word-memory, each having its seat of registration in a well-defined part of the cortex. The first is the (1) auditory word-center, where the sound of words is registered; (2) a visual word-center, where the visual images of letters and words are registered; (3) a glosso-kinæsthetic center, where the combined impressions which pass to the brain as a result of the movements of the lips, tongue, palate, larynx, and other parts concerned in articulate speech, are registered; (4) a cheiro-kinæsthetic center, where sensory impressions resulting from the movements made in writing are stored up. From the glosso-kinæsthetic and cheiro-kinæsthetic center, fibers descend as part of the pyramidal motor tract, those from the glosso-kinæsthetic center going to the motor-speech apparatus in the medulla, and those from the cheiro-kinæsthetic center going to the spinal-motor ganglia concerned in the act of writing. As is known, the auditory word-center is in the first temporal convolution, the visual word-center in the gyrus angularis and a part of the supramarginal gyrus, the speech-center in the third left frontal convolution, and the writing center in the posterior part of the second frontal convolution.

The auditory word-center is the first called into activity; then the speech-center is gradually organized under the influence of excitations coming from the auditory word-center. After a year or two the child's visual word-center becomes organized, and the child recognizes letters and words, and at the same time two sets of association-channels, commissural fibers, are laid down between the auditory word-center and this visual word-center. Finally, the child reads; then there must be activity first in the visual word-center, then in the auditory word-center, and immediately afterwards in the glosso-kinæsthetic center. Then, as the child learns to write, the cheiro-kinæsthetic center becomes organized, the guiding influence of the visual center being called into play, and this would lead to a development of commissural channels between the two centers. The visual center holds the same sort of relation to the act of writing that the auditory word-center holds to articulate speech. In writing from dictation, the train of activity starts in the hearing word-center, spreads to the visual word-center, thence to the cheiro-kinæsthetic center, where the efferent stimuli pass over to the spinal motor centers (Bastian, Allbutt's System of Medicine, vol. VIII).

The chief varieties of aphasia are:—

- Motor aphasia
  - aphemia.
  - agraphia.
- Sensory aphasia
  - visual.
  - auditory.
- Conduction aphasia.

Auditory Aphasia.—Supposing the patient's hearing is perfect, then auditory aphasia is revealed by his inability to put out his tongue.

Visual Aphasia (Alexia).—Supposing the patient can see perfectly, can the patient understand written or printed words? If he fails to do so, he has alexia.

Motor Aphasia (Aphemia).—If he can speak voluntarily, can he repeat words or read aloud? If he cannot, he has aphemia.

Agraphia.—Supposing the patient can write voluntarily, can he write from dictation or from copy? If he cannot, he has agraphia.

A symptom found in all cases of aphasia: if he cannot write voluntarily, because of inability to remember words, but can write from dictation, it is sensory agraphia. If he cannot write either voluntarily or from dictation, it is motor agraphia.

If he uses one word for another, so that the result is unintelligible, then there is paraphasia.

If he writes, and he uses one word for another, so that it is unintelligible, then para-agraphia.

Paraphasia and paragraphia are symptoms of conduction aphasia, lesion of commissural fibers, and the lesion is ordinarily in the island of Reil or the convolutions about the fissure of Sylvius.

Motor Aphasia.—If the patient can read silently, write voluntarily, write from dictation, copy and hear and understand spoken words, but cannot speak voluntarily, repeat words or read aloud, then the lesion is in Broca's convolution, third frontal (motor aphasia, aphemia).

If the patient can hear and understand spoken words, read and understand written or printed words and copy, but cannot speak voluntarily, repeat words, read aloud, write voluntarily or from dictation (aphemia plus agraphia), there is a lesion of the third left frontal convolution. This is the most frequent form of aphasia.

Visual Aphasia.—If the patient can speak voluntarily and understand spoken words, but cannot understand written or printed words, write voluntarily or from dictation or from copy (visual aphasia plus agraphia), there is a lesion in the angular gyrus and supramarginal lobe.

Auditory Aphasia.—If the patient can speak voluntarily, read intelligently, and write voluntarily, but cannot understand spoken words, repeat words or write from dictation (auditory aphasia), then there is a small subcortical lesion of the first and second temporal convolutions. (Butler's Diagnostics).

CHAPTER XIII.

ELECTRO-PHYSIOLOGY.

ELECTRICITY.

Electrical Measurements.

THE system of electrical measurements now in use is founded on the centimeter as the unit of length, the gramme as the unit of mass, and the mean solar second as the unit of time. This is commonly designated as the C. G. S. system.

The ampere is the unit of current; the unit of electromotive force, the volt; the unit of resistance, the ohm.

The ampere is equal to one-tenth of the C. G. S. unit of current, or approximately the current of an ordinary Daniell cell through an ohm. The volt is 100,000,000 times the C. G. S. unit of electromotor force, or approximately the electromotive force of a Daniell cell. The ohm is the resistance of a column of pure mercury 1 millimeter square and 1063 millimeters in length, at zero degrees C.

To Measure Work.—To measure work of contracting muscle, the millimeter-gramme is the unit in the metrical system as that work required to overcome a force equal in weight of one gramme acting through the space of one millimeter.

Cells or Batteries.—1. *Daniell Cell.*—The first constructed constant battery. It consists of a glass jar filled with concentrated solution of sulphate of copper, bathing an unclosed ring of sheet copper around a porous earthen jar filled with sulphuric acid (1 to 10 of water), in which is immersed a rod of zinc. The zinc pole is the negative or the cathode, and the copper pole the positive or the anode, and its electromotive force (E. M. F.) is about 1.07 volts. On account of the constancy of the battery it is the one chiefly used in laboratories of physiology.

2. *Dry Cells.*—The just-described wet cell gives off fumes, contains acids, and must be prepared for use. As the dry cell is always ready and without the preceding disadvantages, it is used extensively in the laboratory. The dry cells are usually modified Leclanché batteries. The Leclanché cell consists of a glass jar containing a saturated solution of ammonium chloride, into which an amalgamated zinc rod dips. The zinc is negative and the carbon positive. The plate of carbon is fitted into a porous pot packed with

pieces of carbon and dioxide of manganese. Its electromotive force is 1.5 volts. The dry cell is usually made of a zinc cup lined with plaster of Paris, saturated with amomnium chloride. A carbon plate is placed in the center of this and surrounded with black oxide of manganese.

Polarization of Plates.—The voltaic battery consists of two metals, zinc and copper, which are surrounded by an electrolyte containing various ions. The positive ions, Cu and H, will work their way towards the positive element, the copper plate, and the OH and SO_4, being negative ions, will go towards the zinc. The hydrogen gas settles in minute bubbles upon the surface of the copper plate and at once interferes with the action of the battery. It interferes both by the resistance it offers to the passage of the current, and also by setting up a current in an opposite direction, which tends to weaken the original current by neutralization. This action is called polarization of the plates. Besides this, in such an element some of the sulphate of zinc produced in the element is attacked by the hydrogen and deposited on the copper plate, so that the copper plate begins to approach the condition of the zinc plate, and, of course, the difference of potential or electromotive force is reduced. In all these ways the current is diminished and the cell is not of constant strength.

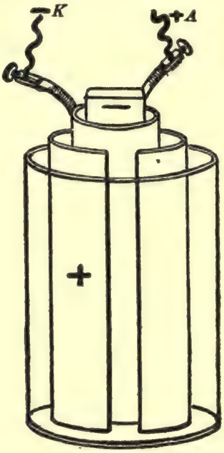


Fig. 214.—Daniell Cell.

Polarization in the Daniell cell is overcome by the solution of copper sulphate, and in the Leclanché cell by the manganese dioxide.

Resistances.—There are two kinds of resistance to electric currents: Internal resistance or the resistance of the element, or the resistance the current experiences in passing through the liquid of the cell from one plate to another; and external resistance, or the resistance the current meets with in passing through the electrodes and apparatus. Internal resistance is inversely proportional to the size of the cell, and directly proportional to their distance from one another; that is, the larger the plate the less the resistance, and the greater the distance the greater the resistance, the conducting power of the liquid being always the same. External resistance depends on the conductivity of the conductor, which is a constant quantity for each conductor. External resistance is directly proportional to the length of the conductor and inversely proportional to the cross-section; that is, the longer the conductor the greater the resistance, and the thicker the (wire) conductor the less the resistance. The thinner the wire the greater is the resistance.

Batteries may be united together as positive pole to negative pole. Here the voltage is equal to the voltage of a single cell multiplied by the number of cells. This method of coupling is used in the medical battery for the application of the galvanic or constant current to man. Another method is to couple abreast or "in multiple arc." Here the positive poles are on one wire and the negative on another wire. Here we have, as a matter of fact, a single cell with plates as many times larger as we have taken cells. The electromotive force is not altered, since the electromotive force of a cell varies with its chemical constituents and not with the size of the cell. Now, the internal resistance of a cell is inversely proportional to the size of the plates, so that by multiplying the size of the plates by the number of cells, say six, then the internal resistance is practically diminished one-sixth. Increased quantity of current is, therefore, obtained.

The human body opposes to the electric current so great an external resistance that the internal resistance of the battery can be overlooked; hence surface extent of the zincs can be neglected. The intensity of the current is determined by the number of the elements and not by their size, hence you couple in series. When, however, you employ electricity to heat the galvano-cautery wire, which is short and of feeble external resistance, you augment the intensity of the current by increasing the surface (size) of the zincs. It is true you do not augment the electromotive force; but as the resistances diminish in proportion to the increase of size of the zinc, the intensity of the current increases in proportion to the increase of size of the zincs. You can have an apparatus to heat the cautery wire by coupling cells abreast or in multiple arc, which amounts to the same thing as having a cell with large-sized zincs.

To summarize: to obtain increased intensity of current with small external resistance, as in a cautery wire, either use large cells or couple a number of cells abreast or in multiple arc; with great external resistance, as in the application of the galvanic current to the human body or the nerves of an animal, you couple the cells in series, small elements being as good as large. One centimeter of nerve offers a resistance of about 80,000 ohms and nonpolarizable electrodes have a resistance equal to 700 ohms each.

Ohm's Law.—G. S. Ohm, in 1827, formulated a law:—

Current strength (amperes) C. =

$$\begin{array}{l} \text{E. M. F.} = \text{Electromotive force (volts).} \\ \hline \qquad \text{R} \qquad = \text{Resistance (ohms).} \end{array}$$

But, there are two resistances, so let R stand for internal resistance and *r* for external resistance; the law will be

$$C = \frac{\text{E. M. F.}}{R + r}$$

The ohm, the ampere, and the volt are closely related, and if any two of them are known with reference to any particular electric current, the value of the third may be readily inferred.

Currents are measured in amperes, resistances in ohms.

Electromotive force is the force which tends to move electricity from a higher to a lower potential. The unit of electromotive force is the volt, and, therefore, is the measure of electrical pressure.

Electromotive force is "difference in potential." A volt is that amount of electrical energy which will produce one ampere of current after overcoming one ohm of resistance.

Then:—

Volts = amperes × ohms.
Amperes = volts ÷ ohms.
Ohms = volts ÷ amperes.

The small Daniell cell has 4 ohms resistance and a current of $^1/_4$ ampere.

"The difference of potential may be compared to the difference of water-level between a reservoir and its distributing pipes. It produces an electromotive force comparable to the force which moves the water from a higher to a lower level. The unit of electrical pressure is the volt. The flow through a hydraulic system is measured by the quantity of water passing any point in a given time; similarly, the quantity of electricity is the amount that flows through a cross-section of the conductor in a given time. The unit of quantity is the ampere." Roughly speaking, your bladder filled with urine may be a volt, the ohm may be a stricture, and an ampere the passing stream of urine or the unit of measure of the amount of urine passing through an object in a second of time.

Electrodes.—To carry the current from the different metals or carbons we have wires covered with cotton, or silk, or gutta-percha, which are attached to the metals or carbon; they are then called electrodes.

Polarization of Electrodes.—In electrolysis of the lymph by the current in a tissue there are produced positive and negative ions in the lymph, which act on the electrodes. If a pair of clean platinum-wire electrodes have been immersed in water and have been conveying a current for decomposition, the positive pole will, after some time, become covered with bubbles of oxygen, while the negative will have collected on it hydrogen gas. If now these electrodes be suddenly disconnected with the battery and connected with a galvanometer, the needle of the galvanometer will deviate in such a way as to show a current in an opposite direction to the original battery current. This is caused by the coating of the negative pole with hydrogen, making it positive, and a current runs from the electrode covered with hydrogen to the electrode covered with oxygen; that is, it runs in an opposite direction to the original current when the battery was attached to the electrodes. This current will naturally weaken the original battery current. This occurrence is called polarization of electrodes. In the same way, if a fresh muscle or nerve be laid across two copper wires carrying a battery current, and these be connected with a galvanometer (previously disconnecting the

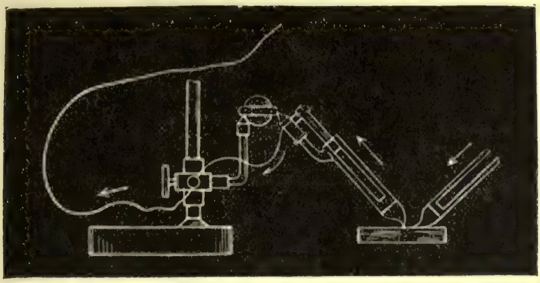


Fig. 215.—DuBois Nonpolarizable Electrodes. (LAHOUSSE.)

battery), a deviation of the galvanometer-needle will be apparent, showing a reversal of direction of current, as was the case with the electrodes in water. To get rid of this current, due to polarization of the electrodes by the tissue of the muscle or nerve, it was necessary to employ electrodes which were unpolarizable. Regnault found these to be zinc immersed in a strong solution of zinc sulphate. DuBois-Reymond constructed electrodes upon this plan. They are usually made by taking two small pieces of glass tubing, open at both ends and curved. One end of the tube is plugged with modeling clay, moistened with salt solution, and then the tube is filled with a saturated solution of sulphate of zinc in which is immersed a rod of amalgamated zinc and to which one of the wires of the circuit is attached. The non-polarizable electrodes of Porter's are porous, boot-shaped cups filled with saturated solution of sulphate of zinc, in which is plunged a zinc rod.

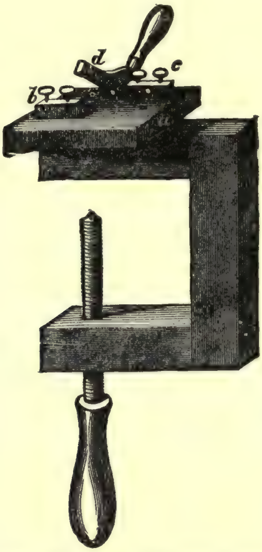


Fig. 216.—Tetanizing Key of DuBois-Reymond. (After Rosenthal.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

Wires may be attached at *b* and *c*. When *d* is down the current is "short-circuited," *i.e.*, does not pass through the wires, but direct from *c* through *d* to *b*, or the reverse, since *b*, *c*, *d* are of metal and, on account of their greater cross-section, conduct so much more readily than the wires. *a* Is an insulating plate of ebonite. This form of key is adapted for attachment to a table, etc.

After the use of the unpolarizable electrodes the boot should be emptied, rinsed in tap water, cleaned, and placed in several hundred cubic centimeters of normal saline until wanted. If the boot is kept saturated with normal saline, the electrodes will remain non-polarizable.

Detector, or Galvanoscope, or Current Indicator.—Use a vertical galvanoscope, in which the magnetic needle is so loaded as to rest in a vertical position. It consists of a magnetized needle, surmounted by a coil of wire. It indicates the passage and direction of a current. It really is a little galvanometer. Now, connect the wires from the positive (+) and negative (—) poles of a battery with the binding screws, and note, when the circuit is closed, the needle deviates from its vertical position.

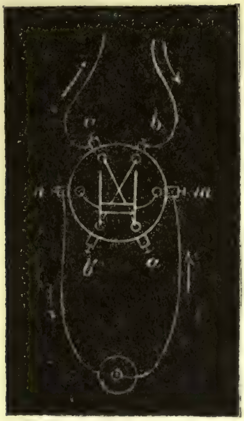


Fig. 217.—Pohl's Commutator. (Lahousse.)

Keys.—When we wish to make or break a current by hand we use keys. DuBois key consists of two metal blocks, each carrying two binding-screws fitted on a base of hard rubber, which acts as an insulator. These two blocks of metal are connected by a metal cross-bar which thus closes the key. It is employed in two ways. In one, it breaks the current going from the cell to the nerve; when the key is closed the current is made, when the key is open the current is broken. In the other way, the current from the cell passes through the key when it is closed and then it is a short-circuiting key, because the current going through the electrodes from the short-circuiting key to the nerve meets here a body (the nerve) which opposes a great resistance to the passage of the electrical current, and, as electricity always takes the easiest way home, it goes through the conductor offering the smaller resistance, the brass key. If the key is open, then the whole current passes to the nerve. This method of using the key is known as "short-circuiting." In using the key to apply an induction or Faradic current to excite a nerve or muscle, always use this method; that is, place a short-circuiting key in the secondary circuit to prevent unipolar action.

Mercury Key.—Where a fluid contact is required the wires dip into the mercury. It is used in the same way as the DuBois key, for make-and-break shocks.

Commutators.—Pohl's commutator is used for sending (1) a current into two different pairs of wires; (2) for reversing the direction of the current in a pair of wires; (3) it can also be used as a mercury key. It consist of a round block of wood with six cups, each containing a binding-screw. Between two of these stretches is a bridge insulated in the middle. The battery is attached to the leading-in wires, and, as the bridge is rocked from one side to the other, the current is sent through one or the other pair of wires. To reverse the direction of a current, only one pair of leading-out wires, besides the cell wires, is attached to the binding-screws of the mercury cups. Then the cross bars are inserted, which change the direction of the current on rocking the bridge.

Induction or Faradic Currents.

DuBois-Reymond's Induction Apparatus.—It consists of a primary spiral of about 130 coils of a moderately thick silk-covered copper wire, and of a secondary spiral of some 6000 coils of silk-covered copper wire of a thickness of about a tenth of a millimeter. The core inside the primary spiral is formed by a bundle of thin iron wires, each carefully coated with shellac varnish. To graduate the strength of the induced current of the secondary spiral, the secondary spiral is moved in a groove of wood from or towards the primary spiral, and the distance between the spirals is graduated in centimeters and millimeters, or the secondary spiral is rotated as by Bowditch. To make or close, or to break or open the circuit coming from the cell through the primary spiral, the electro-magnetic hammer of Neef is used to give us repeated shocks, or the interrupted current. When single induction shocks are used, the wires from the battery are connected with a key and this, again, with the two terminals of the primary spiral. The action of the coil of wires depends upon the fact that the strength of a current running along a wire will be altered and an induced current set up in a second wire placed near it. The strength of the induced current may be increased by placing a bundle of soft iron wires in the interior of the primary coil. By using a large number of turns of wire in each coil the effect is greatly increased, because each turn of the primary coil induces a current in each of the turns of the second, and all these small effects summed up produce a single greatly increased effect. The opening shock is stronger than the closing shock, so that if repeated induction shocks are sent through a tissue for some time polarization effects are set up. To

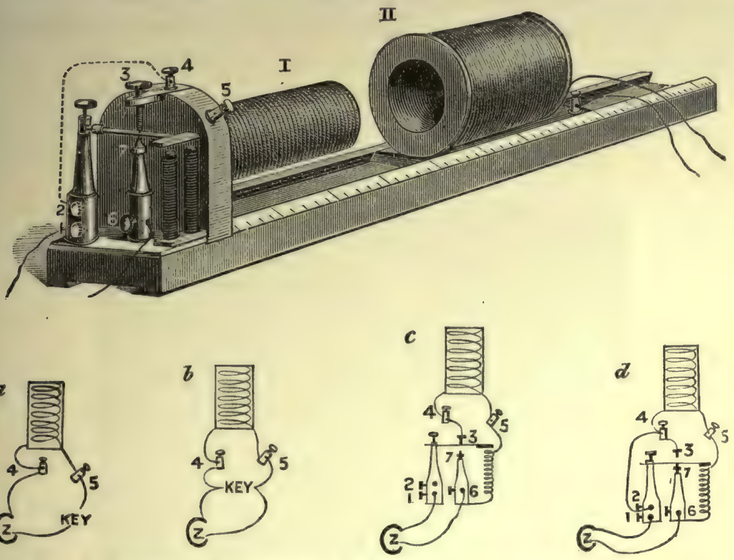


Fig. 218.—DuBois-Reymond's Induction Apparatus. (Waller.)

The numbers 1 to 7 indicate the terminals and contact screws connected with the primary coil.

For single shocks the two battery wires are to be connected with the terminals 4 and 5, which are at the two ends of the primary wire.

(*a*) *Unmodified shocks* are obtained when a key is used to interrupt one of the wires.

(*b*) *Reduced shocks* are obtained when a key is used short-circuiting the primary wire.

(*c*) *For repeated shocks* (*ordinary*) the two battery wires are to be inserted at 1 and 6. The circuit now includes the spring interrupter and the wire of the electro-magnet by which the circuit is made and broken at the contact screw 3; the contact screw 7 is kept out of use by being lowered.

(*d*) *For repeated shocks* (*modified*) the battery wires are left, as before, at 1 and 6. A short, thick side wire is placed between 2 and 4. The contact screw 3 is raised out of range of the spring, and the contact screw 7 is raised until it comes within range of the spring.

The electrode wires are in each case connected with two terminals (not seen in figure) forming the two ends of the secondary wire.

equalize the shocks, Helmholtz used a modification consisting of a "side wire." Helmholtz's side-wire and the modifications it introduces into the induction apparatus should be used when induced currents are applied to nerves. By this contrivance we diminish two possible mistakes: (1) the undesirable predominance of currents in one direction, that is, in that of the break; (2) unipolar stimulation. Helmholtz's side-wire acts by short-circuiting instead of completely breaking the battery current.

Unipolar Induction.—If you remove one of the wires of the electrodes of the secondary coil, so that only one electrode is connected with that coil, and slide the coil towards the primary coil, then send a strong current through Neef's hammer and the primary coil, shocks will be faintly felt by the tongue, though only one electrode is attached to the secondary coil. It is on account of this possibility of stimulating through only one pole that a short-circuiting key is always used in the secondary spiral current. In the primary or battery current a simple key is used, for a short-circuiting key would let the battery quickly run down.

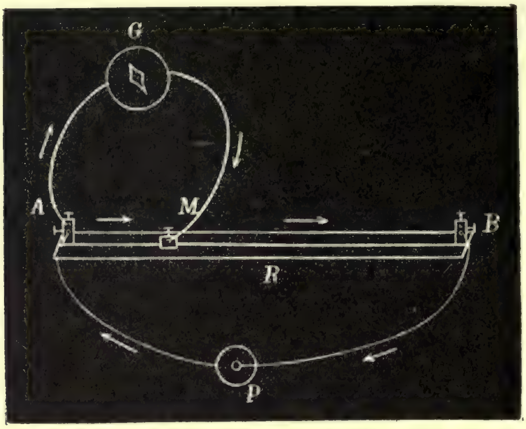


Fig. 219.—Principle of Simple Rheocord.

G, Galvanometer. *R*, Rheocord. *P*, Battery.

Rheocord.—A rheocord is an apparatus for dividing a constant current by offering a circuit of relatively small resistance, which is capable of being varied so that a variable part only of the current shall pass through the experimental circuit. It usually consists of a platinum wire of known resistance, to the ends of which the battery poles are connected. With one of these ends another wire is connected. This forms part of the experimental circuit through which a portion of the battery current is to be conducted. This current is completed through a wire attached to a rider which slides along the rheocord wire. The other portion of the current goes through unpolarizable electrodes to a nerve lying across them. The amount of current passing through the nerve varies directly with the resistance of the deriving circuit, the rheocord. By increasing this resistance more current is sent through the nerve, and on diminishing, less.

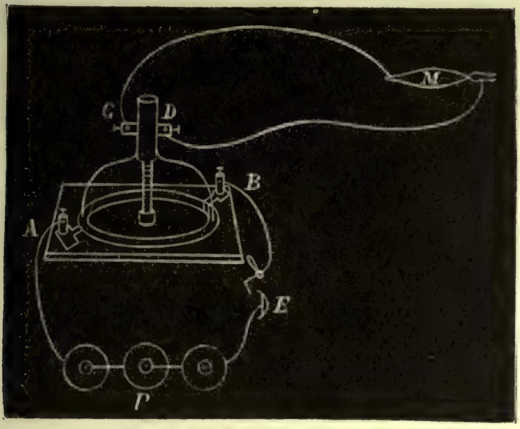


Fig. 220.—Schema of Apparatus to Study Influence of Rapid Variations of the Constant Current by the Rheonome of von Fleischl. (LAHOUSSE.)

P, Daniell cells. *E*, Key. *A*, *B*, Two pieces of zinc to which the wires are attached. *C*, *D*, These two points are united by wires to the muscle *M*.

Suppose, for example, that the resistance of the electrode and nerve is 100,000 ohms and the resistance of the rheocord 5 ohms, then $\frac{100,000}{100,005}$ of the current passes through the rheocord and $\frac{5}{100,005}$ through the nerve.

Rheonome of Von Fleischl.—The rheonome of Von Feischl consists of an ebonite plate with a circular groove on its upper surface. This groove is connected at diametrically opposite points to the binding-screws. In the center of the ebonite plate is a vertical rod whose upper extremity articulates with a piece of ebonite, which is movable and has on its two surfaces two plates of zinc, which are curved in an archlike form. Their upper extremities are united to the bind-

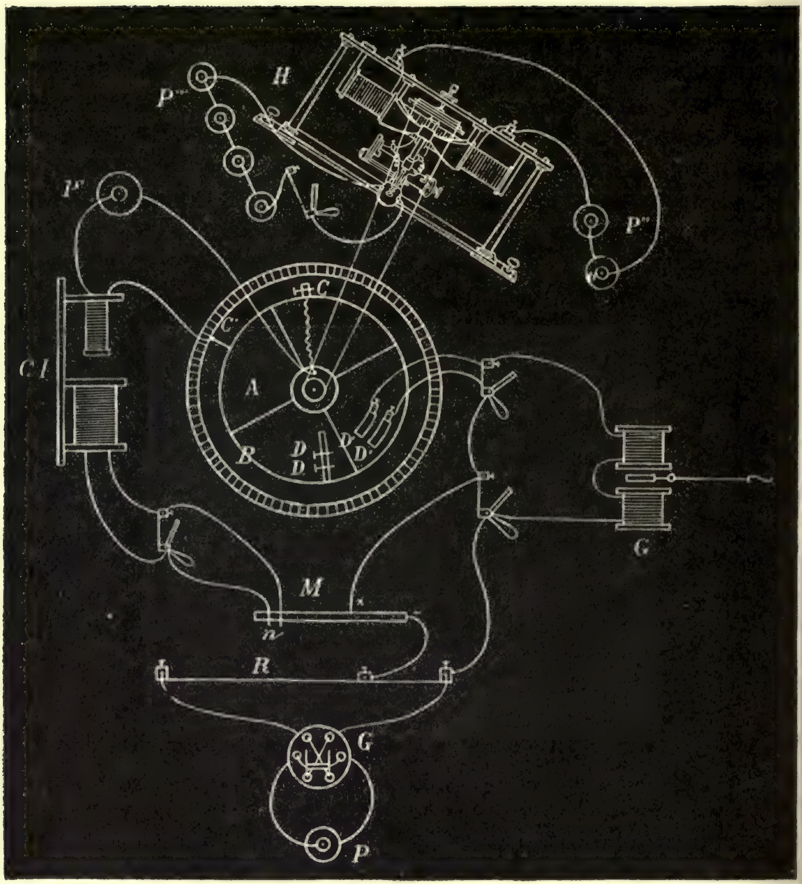


Fig. 221.—Schema of Experiment to Measure the Rapidity of the Muscle Current by the Aid of the Differential Rheotome of Bernstein. (Lahousse.)

M, Muscle prepared in such a manner that by one extremity the muscle current goes to the galvanometer, and to the other extremity electrodes are applied which carry to the muscle an induction current. *G*, Galvanometer.

The rheotome of Bernstein (*A*) consists essentially of a disc (*B*), which is set in uniform and rapid motion by the rotation apparatus of Helmholtz (*H*). At each revolution the needle *C*, striking the wire *C'*, closes and opens rapidly the primary current of the induction apparatus in such a manner as to excite the muscle by a single induction current. On the opposite side of the disc lie two needles (*D*, *D*) which, dipping in the two cups of mercury (*D'*, *D'*), close for a very short time the circuit of the muscle current. If the rapidity of rotation of the disc is known and the interval which elapses between the time of excitation of the muscle, that is, the time when the needle (*C*) strikes against the wire (*C'*), and the beginning of the closing of the muscle current, that is, the time when the two needles (*D*, *D*) commence to dip into the mercury cups (*D'*, *D'*), then the rapidity of the propagation of the negative wave or variation is easily calculated.

ing-screws, and their lower extremities dip into the groove filled with a saturated solution of sulphate of zinc. The arched plates are called the bridge. Three Daniell cells are connected to the binding-screws, with the interposition of a key. The binding-screws are united to electrodes upon which lie the nerve-muscle preparation. When the key is closed the muscle contracts and in the interval relaxes, except when there is a rotation of the bridge.

Then suddenly rotate the handle with its two zinc arms. This is equivalent to a sudden variation of the intensity of the current, the current, of course, continuing to pass all the time. The muscle suddenly contracts. The response of a muscle or nerve to electrical stimulation is due not to the simple flow or intensity of a current through the tissues, but rather to the more or less sudden change in the strength of the current. Sudden increase or decrease may act as an efficient stimulus, but the gradual increase or decrease of the current causes no response (Du Bois's law.)

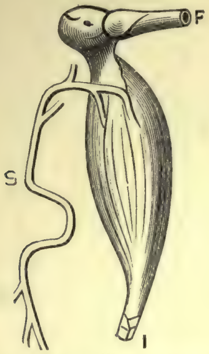


Fig. 222.—The Nerve-muscle Preparation. (STIRLING.)

S, The nerve-muscle. *F*, Lower third of femur. *I*, Tendon of gastrocnemius muscle.

Differential Rheotome.—The rheotome of Bernstein is an instrument by which a series of stimuli can be led into a nerve or muscle, and the consequent excitatory effects led off to a galvanometer during definite periods at regular intervals after stimulation.

ELECTRO-PHYSIOLOGY.

Animals and plants have, as a general phenomenon, electricity, the potential energy of living matter. In the animal the nerves, muscles, and glands are the special seats of the electrical properties. A muscle has three forms of energy—work, heat, and electro-motor activity. To study animal electricity, it is necessary to use the instruments employed in the physical laboratory, but they have to be made very sensitive, since the electric potential is feeble in animals. There are usually employed three methods of revealing animal electricity: (1) the physiological rheoscope; (2) the galvanometer; (3) the capillary electrometer.

Physiological Rheoscope.—This name has been given to the nerve-muscle preparation of the frog where the greatest possible length of the sciatic nerve attached may be used. The preparation of the nerve requires special care, for the nerve must be removed by a little seeker of glass or bone. No metal must touch it. It is removed from below upward, and if properly done there should be no contraction of the muscle during the operation. If the nerve of this preparation be brought into contact with a segment of separated muscle so as to touch simultaneously the longitudinal and transverse surfaces, a contraction instantly follows.

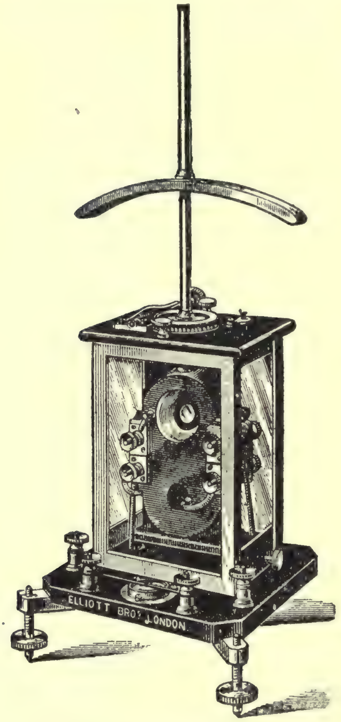


Fig. 223.—Thompson Galvanometer.

Galvanometer.—The instrument usually employed is Thompson's astatic, high-resistance, reflecting galvanometer. In this instrument a pair of suspended magnets nearly astatic are surrounded by many windings of fine, insulated wire with a resistance equal to 10,000 to 20,000 ohms, which explains the name of high-resistance galvanometer. Because it has on the upper magnet a slightly concave mirror by which a ray of light can be reflected on a scale, it is also called reflecting. By placing the point of the unpolarizable electrode on the center of the longitudinal surface of the muscle, and the other electrode over the center of the freshly divided transverse surface of the muscle, and connecting the electrodes with the galvanometer, with a shunt interposed between the electrodes and the galvanometer, it will be seen that the needle of the galvanometer deviates. By noting the deflection of the needle, it is found that the longitudinal surface of the muscle is positive and the transverse section is negative. The deflection of the needle is caused by the current of injury by the transverse section of the muscle. It is called the demarcation current, because the difference of potential appears at the demarcation between the dying and the injured muscle. The injured part of the muscle is negative to the uninjured part and the current in the galvanometer is from the longitudinal (positive) surface to the uninjured negative transverse surface.

Capillary Electrometer.—This instrument is an electrical manometer and shows electrical pressure. It consists mainly of a glass tube ending in a fine point, which is partly filled with clean mercury and then placed in communication with a pressure apparatus. The capillary end of the glass tube dips into a tube containing mercury and a 20-per-cent. solution of sulphuric acid. Into the tube with sulphuric acid is fused a platinum wire which forms one connection with the lower column of mercury. Another platinum wire is connected with the capillary tube. Anything which alters the surface tension will cause the mercury to move. If now two unpolarizable electrodes are connected with a capillary electrometer with a short-circuiting key, and the center of a muscle is laid on one of the non-polarizable electrodes and the divided transverse end on another non-polarizable electrode, then when the mercury meniscus is watched

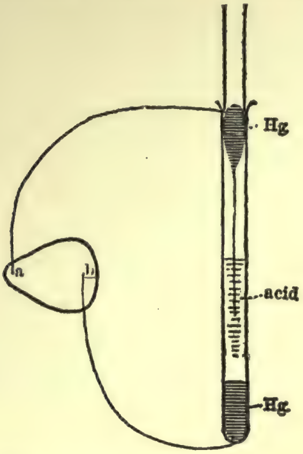


Fig. 224.—Diagram of Capillary Electrometer. (STARLING.)

Hg., Mercury. The two terminals are represented as leading off two points at the base and apex of a frog's heart, *a b*.

with a low-power microscope the mercury will move in a direction showing a higher potential at the positive electrode on the longitudinal surface.

Instead of a transverse section of a muscle its tendon may be taken, which is also negative and has been called the natural transverse surface. The cut surface of a longitudinal section of muscle presents positive electrization. The laws of electrical currents of muscle have been fully determined by DuBois-Reymond:—

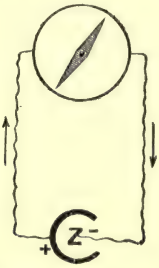


Fig. 225.—Direction of Current of Daniell Cell.

Through the galvanometer the current is from copper to zinc. Through the cell the current is from zinc to copper.

1. When the conductor unites the longitudinal to the transverse surface there is a well-marked deviation of the needle, and the greatest deviation occurs when the middle of the longitudinal surface is connected with the middle of the transverse.

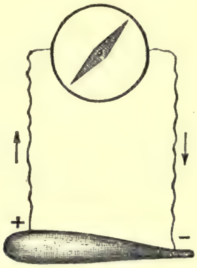


Fig. 226.—Direction of Current of Injured Muscle. (Waller.)

Through the galvanometer the current is from normal to injured part, or from resting to active part. Through the muscle the current is from injured to normal part or from active to resting part.

2. When two points are connected on a longitudinal or transverse surface which are unequally distant from the middle, or two points unequally distant on opposed surfaces, then there is a slight deflection of the needle. In the case of the longitudinal surfaces the

current passes along the conductor from the point nearer the center to the one farther off. The reverse is the case for the transverse.

3. When two points are connected on the same or on opposed surfaces equally distant from the center, or when the centers of two opposite surfaces are joined, there is no movement of the needle of the galvanometer.

The parelectronomic part of the muscle is the tendinous part of the muscle, which is negative instead of being positive, as is the rule. Here it is necessary to make an artificial section for the purpose of demonstrating the electrical phenomena of muscle.

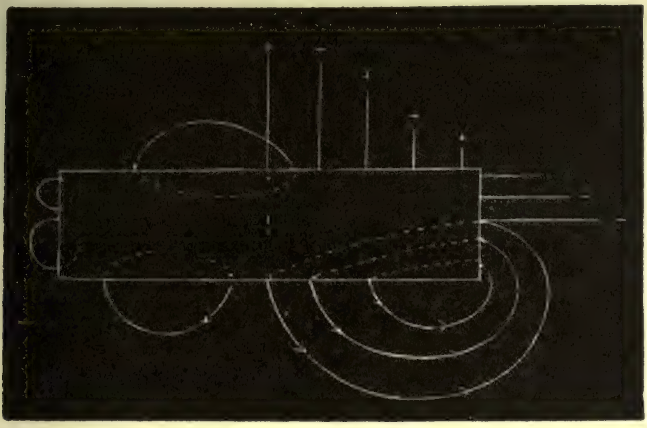


Fig. 227.—Schema Representing the Inequalities of Electric Tensions upon the Natural Longitudinal Surface and upon the Artificial Transverse Surface of a Muscle-cylinder. Also the direction of the electric currents from the exterior to the interior of the muscle. (Lahousse.)

Hermann has shown that the muscle-currents (demarcation currents) are the result of the preparation, and do not exist in the normal, intact fibers when in a state of repose. These galvanometrical deviations are due to the traumatic action of air, cold, or chemicals.

Electrical Phenomena of Contracting Muscle.—If upon the electrodes connecting the poles of the galvanometer a muscle is so placed that the needle deflects, then on tetanizing the muscle by stimulating its nerve, the needle will be seen to retrace its movement of deflection. This reverse of the natural current is known as negative deviation. This has been shown to be due to a weakening of the natural muscle-current, and not to the production of a new one contrary to the current of rest. This negative variation can stimulate the nerve of another muscle if the nerve of the physiological rheoscope be placed on the contracting muscle in such a manner that the first touches both the cut surface and another point on the muscle; then each contraction of the muscle is followed by a contraction of frog's nerve-muscle preparation (secondary contraction). This negative variation lasts about 0.004 second and is propagated along the muscle with the same velocity as the wave of contraction it precedes, vanishing even before the arrival of the latter. Hermann calls the negative variation by the name of current activity or action current.

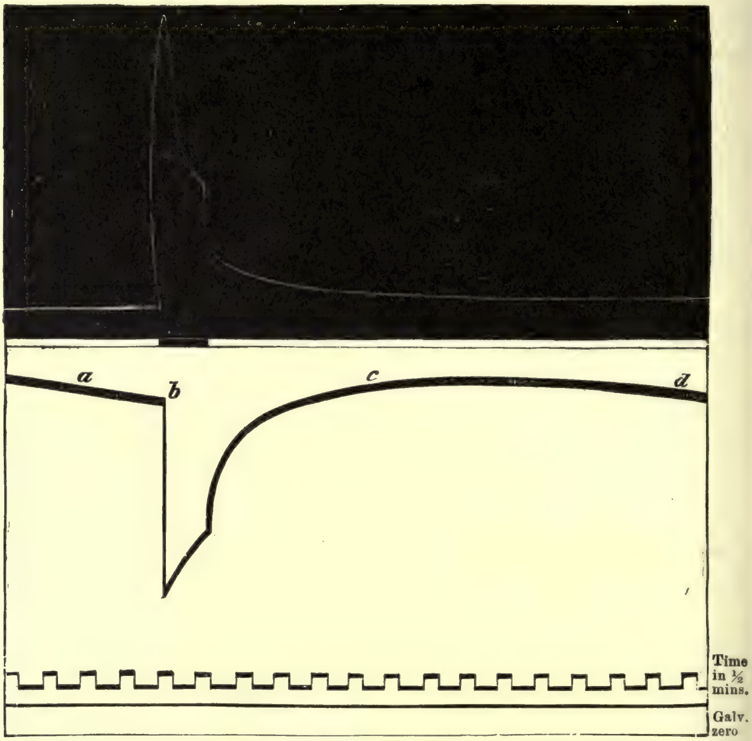


Fig. 228.—The Negative Variation (Frog's Gastrocnemius.) (WALLER.)

Simultaneous record of a tetanic contraction (white line) and of the accompanying negative variation of a current of injury (black line). (*a*) The Current of injury is normally subsiding; (*b*) it is suddenly diminished during tetanus (negative variation); (*c*) it subsequently increases (positive after-variation); and (*d*) it finally resumes its normal decline.

Diphasic Variation.—The base and apex of the heart are connected by unpolarizable electrodes to the capillary electrometer. When the heart contracts, there will be a diphasic variation. The contracted portion at first becomes negative, and then positive, to the part not contracted. The first phase, base is negative to the apex; second phase, apex negative to the base. The diphasic variation follows from the fact that action does not take place at the same time throughout the whole heart, but takes time in its transmission from a point of stimulation.

Nerves.

The nerve presents differences in electric potential similar to that of the muscle, except it is much weaker. Every part of its cut transverse surface is negative, whilst its longitudinal surface is electro-positive. You have muscle-currents; also nerve-currents.

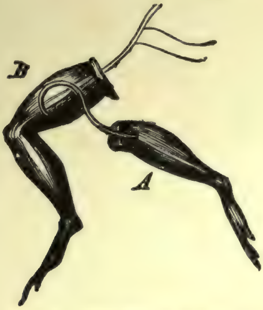


Fig. 229.—Arrangement of Parts to Show Secondary Contraction in Muscle. (After Rosenthal.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

Negative Variation of the Nerve-current or Action-current.—If you place upon the electrodes connected with the galvanometer a piece of nerve, the deviation of the needle shows the existence of the nerve-current already described so long as the nerve is at rest. If you tetanize the nerve the needle is seen to run back toward zero, and sometimes even beyond it. This takes place in every kind of nerve and in the whole length of the nerve. It can be produced by mechanical or chemical stimuli as readily as with electricity. The greater the stimulus, the greater the negative variation, but there is not a definite proportion between them. Hermann has shown that neither in the nerve nor in the muscle do any of these currents exist so long as the structures are uninjured. To generate a nerve-current in repose it is necessary to make a transverse section. This produces death of the superficial layer of a segment next the cut surface. The dead tissue behaves negatively with regard to the living, and the electromotor forces accordingly have their seat at the plane of demarcation between the dead and living. As to the action currents, they are explained by admitting that during stimulation the active parts are negative with regard to the parts at rest.

Waller has compared the action of ether and chloroform on the electrical currents of a nerve. The movements of the galvanometer mirror are photographed. He has shown that chloroform is more toxic than ether by this method.

The nerve had in each case a maximum dose; that is, for a period of one minute, air saturated with the drug, that is about 50 per cent. of ether and about 12 per cent. of chloroform. In the case of ether, the effect was quite typical, an abolition of excitability in about three minutes. In the case of chloroform, the excitability was promptly abolished, and on testing the nerve a half hour afterwards the nerve has definitely lost its excitability; that is, dead by chloroform.

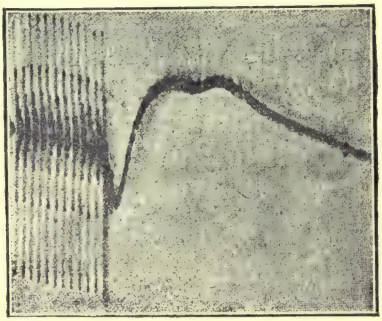


Fig. 230.—Effect of Chloroform upon the Electrical Responses of Isolated Nerve. (Waller.)

The electrical response is definitely abolished; there is no recovery during the period of observation. With ether it gradually recovered.

Theories of Muscle and Nerve Electrical Currents.—There are two theories, one of Du Bois-Reymond, the molecular, the other that of Hermann, that of alteration.

Molecular Theory.—The molecules may be considered to be positive on their longitudinal surface, and negative on their transverse section. Their negative surface is turned towards the ends of the muscle or nerve, and the positive surfaces directed towards the longitudinal surface. They are surrounded by a non-electric conducting surface. When an electrode is placed on the longitudinal surface and would touch the positive side of the molecules, the other electrode on the transverse section would be in contact with the negative side.

Alteration Hypothesis.—It was shown that muscle not injured exhibited no electrical current. Hermann states that these currents are due to the chemical constitution of the tissue at the cross-section. He believes that the current is the result of injury, causing death of a small part of the muscle fiber at the cross-section, and so producing differences in potential. The difference of potential arises at the demarcation between dying and injured muscle; hence the name "demarcation current." The dying portion of the cross-section of the muscle behaves negatively to the living, and the electromotive force has its seat in the demarcation zone between the living and dying.

Hering is in accord with DuBois-Reymond, that the normal resting muscle is the seat of electromotor forces which are not exhibited. The electrical currents are due to chemical changes in the tissues. Anabolism causes a positive electrical phenomenon, and katabolism a negative condition of the part. The majority of physiologists have accepted the alteration theory as the one explaining the majority of the facts observed.

Neither theory explains all the facts.

CHAPTER XIV.

THE ANATOMY AND PHYSIOLOGY OF THE NERVOUS SYSTEM.

ANATOMY OF THE NERVOUS SYSTEM (EXCEPT THE CEREBELLUM).[1]

STRUCTURE OF NERVE-TISSUE.

Nerve-tissues present themselves in two varieties: some as *white* substance and some as *gray* substance. These two substances are different, not only in color, but also in physical and chemical properties and in anatomical arrangement.

The gray substance contains as characteristic elements the *nerve-cells;* the white substance, the *nerve-fibers.* These latter emerge from the gray nervous substance to branch out toward the peripheral organs. These two substances, gray and white, possess a common element known as *neuroglia;* in addition, each contains blood-vessels.

The Nerve-cell, or Neuron.—The nerve-cell is the characteristic fundamental element of the gray substance: it is an independent unit of the nervous system. It is the element which gives to this kind of nervous tissue its gray color. When these units are charged with a strong portion of pigment, they are black, as in the locus niger of the cerebral peduncles. When a little less pigmented they present a grayish color: the color that is characteristic of the brain and the central portion of the spinal cord. They may be charged with red pigment, then the cells are reddish; such cells constitute the red nucleus of the head of the cerebral crura.

Structure of the Nerve-cell.—The nerve-cell is composed of (1) a mass of protoplasm inclosing a nucleus with its nucleolus; (2) of simple or branched prolongations. The protoplasm of a nerve-cell, like that of many other cells, is formed of a very delicate network of bands whose meshes are filled with a clear or finely granular albuminoid substance. The network has been designated by the name of *spongioplasm* and the intermediate substance is generally termed *hyaloplasm.* As to these two components the protoplasm of nerve-cells is like that of most other cells.

Fibrils.—One peculiarity is the presence in it of fibrils which run *through* its substance.

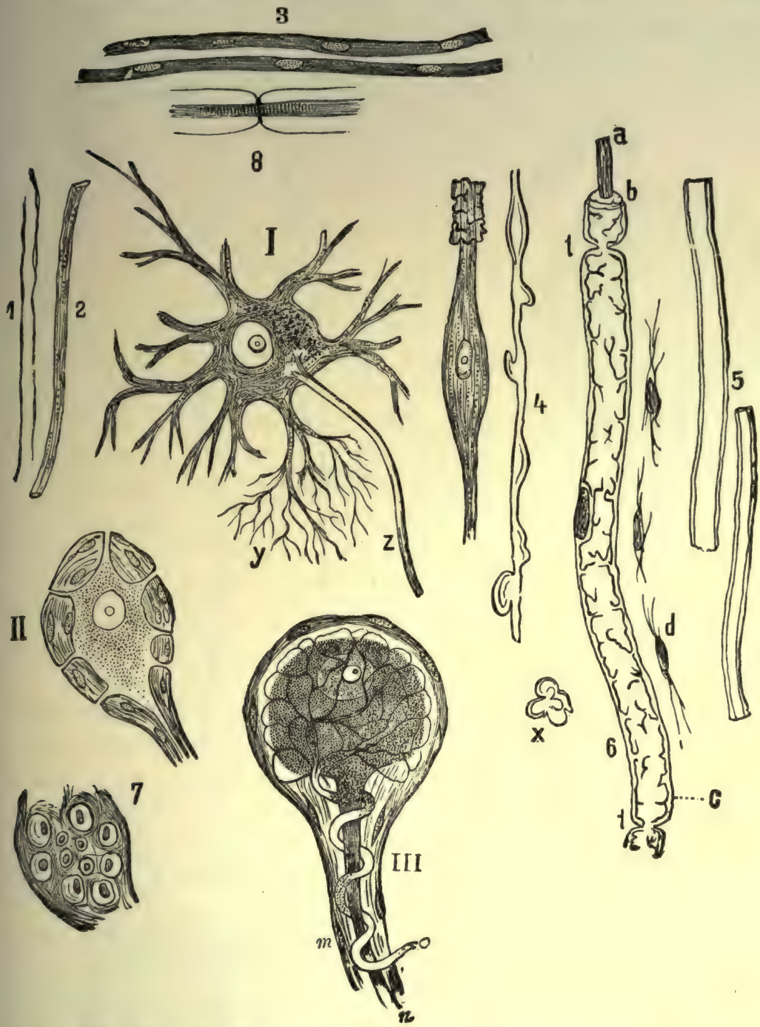


Fig. 231.—The Structure of Nervous Tissue. (Landois.)

1, Primitive fibril. 2, Axis-cylinder. 3, Remak's fiber. 4, Medullated varicose fiber. 5, 6, Medullated fiber with Schwann's sheath. *C*, Neurilemma. *t*, *t*, Ranvier's nodes. *b*, White substance of Schwann. *d*, Cells of the endoneurium. *a*, Axis-cylinder. *x*, Myelin drops. 7, Transverse section of nerve-fiber. 8, Nerve-fiber acted on with silver nitrate. *I*, Multipolar nerve-cell from spinal cord. *z*, Axial cylinder process. *y*, Protoplasmic processes; to the right of it a bipolar cell. *II*, Peripheral ganglionic cell with a connective-tissue capsule. *III*, Ganglionic cell, with *o*, a spiral, and *n*, straight process. *m*, Sheath.

Granules.—The other characteristic feature of nerve-protoplasm is the existence within it of *angular granules*. These show a special liking for basic aniline dyes, as methylene blue. By many

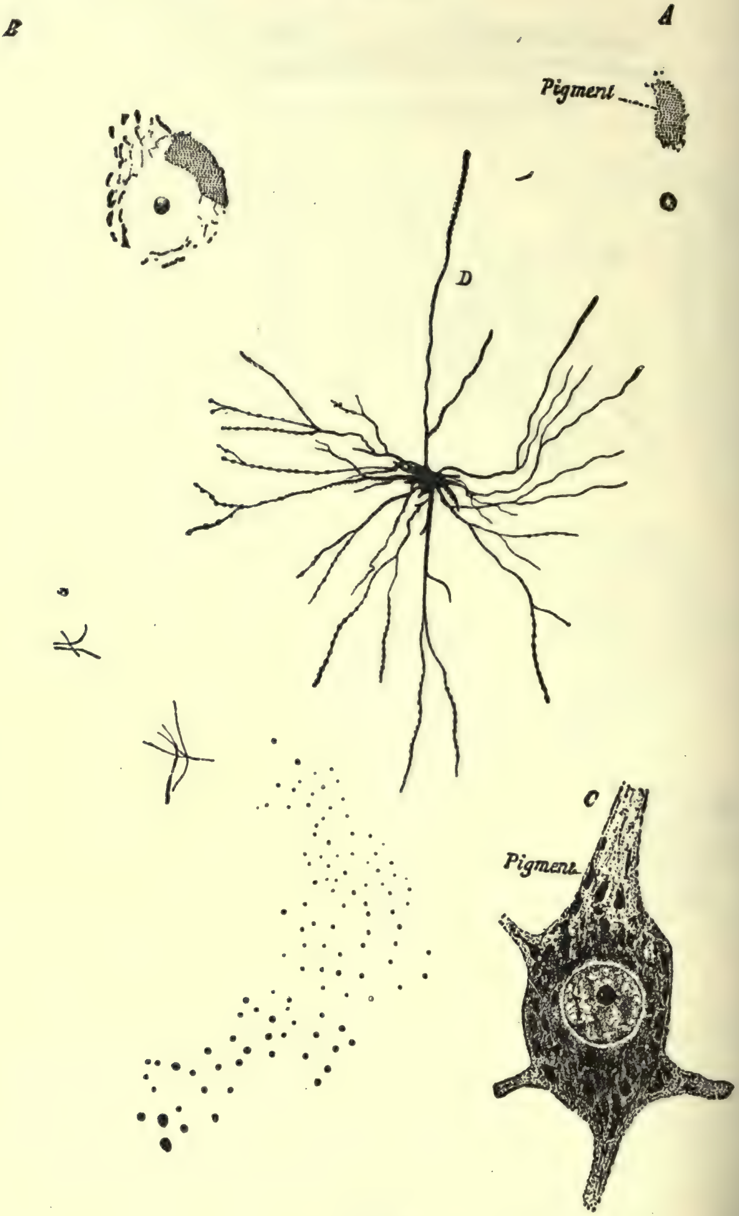


Fig. 232.

A and *B*, Cells from the anterior horn of a human spinal cord. Fixed with alcohol and stained with methyl-blue. *C*, Ganglion-cell fixed with alcohol and stained with hæmatoxylin. *D*, Ganglion-cell from anterior horn of fœtal dog. (After an original preparation by RAMON Y CAJAL.) Prepared with Golgi method. *E*, Neuroglia. (After an original preparation by WEIGERT.)

authors they are spoken of as *Nissl bodies,* after their discoverer and the man who has demonstrated their physiological worth. The granules are found scattered throughout the cell-body and its dendrons, but *not* in the axis-cylinder and the adjacent area of the cell to which it is attached.

The most important relation that these granules bear physiologically to the cell is as follows: Under either normal or abnormal activity of the nerve-cell the granules undergo a change which has been termed *chromatolysis.* It is slow dissolution of the granules with diffusion of the degenerated product into the protoplasm. At first the cell swells, pushing its nucleus to one side; later the cell diminishes in size, due to a loss of its chromatophilic substance.

It is in the hyaloplasm that the pigment substance which gives to the cell its particular color is deposited.

In the discharge of nerve-energy of a nerve-cell, Nissl granules are used up, hence called by Marinesco, kinetoplasm, a source of energy. Nissl granules disappear or undergo chromatolysis after high fever, after epileptic convulsion, or after poisoning by strychnia or the toxins of tetanus germs. During uræmia the cells of the cerebal cortex and of the anterior horns of the spinal cord show chromatolysis. Anæmia produces similiar effects. Fatigue in nerve-cells can be demonstrated by chromatolysis.

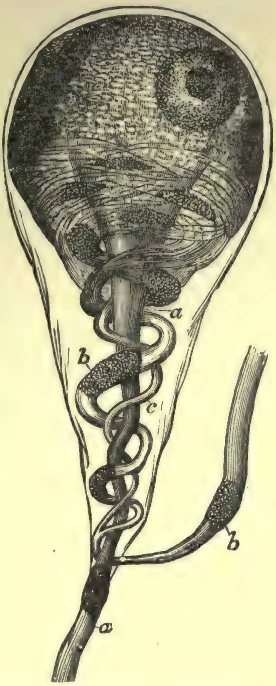


Fig. 233.—Ganglion Cell from Sympathetic Ganglion of Frog; Greatly Magnified, and Showing Both Straight and Coiled Fibers. (After Quain.) (From Mills's "Animal Physiology," copyright, 1889, by D. Appleton and Company.)

Nucleus.—The nucleus of the nerve-cell forms a small, rounded or oval mass. It is characterized by its relatively large size. This nucleus is strongly colored by all the reagents, such as carmine, methylene blue, etc. Around the nucleus the chromatin forms a sort of cell-wall called the nuclear membrane. Within the nucleus is seen a small refracting body called the *nucleolus.* Its chromatin is relatively great in amount.

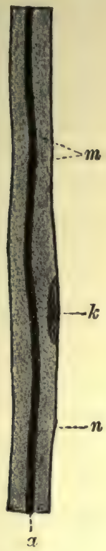
Cell-prolongations.—From the researches of Deiters it has been learned that nearly every nerve-cell has protruding from its periphery a greater or less number of prolongations. These are of two varieties: one is unique, nonbranching, and prolonged under the form of a cylinder-axis of a nerve. It is known by the various terms, *axis-cylinder, neuraxon, Deiters' process,* and *neurite.* The other variety of prolongations is composed of many, though an uncertain, number of processes. This new set of prolongations bears the name of *protoplasmic processes, dendrons, dendrites,* or the *poles of the cells.* Some cells possess no dendrons, others very many. However, it is believed that no cell is without its neuraxon. According to Cajal, the communication of the prolongations of the cells among themselves is no more than that of simple *contact.* It is analogous to the contact which permits of the passage of the electrical current when the two electrodes of an electrical battery are in contact. Further, the nervous impulses are transmitted only along the neuraxons from cell to cell. This neuraxon, by branching and coming in *contact* with the dendrons of other and neighboring cells, conveys its impulse to them. They in turn transmit it centripetally to the axis-cylinders of their own cells to be further transmitted to other cells. The nerve-cell, according to this doctrine, would be physiologically unipolar. To denote this close contact existing between the axis-cylinder and dendrons of various cells, Foster has used the term "synapsis."

Bethe's Theory of Nerve-cell Connections.—According to Bethe, when a nerve is cut the nuclei of the neurilemma can regenerate a new "band-fiber" without union with the central stump. Hence we believe that the axis-cylinder is only an outgrowth from the nerve-cell. According to Bethe, the neuro-fibrils go through the nerve-cells and by a network are placed in direct communication with the neuro-fibrils of other neurons. Here the cell has no direct activity in the conduction of impulses from one part of the nervous system to the other. The neuro-fibrils alone, and the cellular network within and around the nerve-cells with which they connect, form the conducting track that at all points is in continuity.

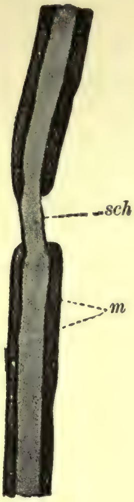
The nerve-cells of the gray matter are of various sizes and shapes, the branched, stellate, or multipolar form being predominant. Some are more or less bipolar or spindle-shaped; however, at each extremity there is usually a fine plexus of branches. Some are ovoid or pyriform, as in the cortex of the cerebellum, where they have received the name of cells of Purkinje. The cells of the ganglia of the spinal nerves are, in great part, unipolar.

The *dimensions* of the nerve-cells are very variable; the smallest are about $^{1}/_{4000}$ inch in diameter, the cells of the posterior horns of the spinal cord are from $^{1}/_{2500}$ to $^{1}/_{1200}$ inch, and the giant cells of the anterior horns of the spinal cord are about $^{1}/_{250}$ inch in diameter.

By employing Golgi's silver-nitrate method of staining, the nerve-cells, with their processes, are stained black from a deposition of the silver. By means of this. the nerve-prolongations may be traced to their ultimate terminations. This method beautifully demonstrates the distribution of the neurites, their branching, and manner of contact with dendrites of contiguous cells; also, how, as a rule, the neuraxon does no very immediate branching. It must be stated, though, that usually from the neuraxon there proceed numerous fine fibrils to which the term *collaterals* is applied. These are in communication with the dendrites of the neighboring cells. In nerve-centers, the neuraxon, after proceeding for some distance, does really



234



235

Fig. 234.—A Piece of Medullated Nerve-fibril of Man, Nucleus and Axis Cylinder Stained by Carmine. (Sobotta.)

a, Axis cylinder. *k*, Nucleus. *m*, Medulla. *n*, Neurilemma (Schwann's sheath).

Fig. 235.—A Piece of Medullated Nerve of Man. It shows Ranvier's Constrictions and Lantermann's Incisures. (Sobotta.)

m, Medulla. *sch*, Ranvier's constrictions.

branch to form arborizations to come into contact with nerve-dendrites.

THE NERVE-FIBERS.—Every nerve-fiber is a process of a nerve-cell. It is the neuraxon of some particular cell. It is the medium which conducts impulses to or from the tissues and organs, on the one hand, and the nerve-centers, on the other. In the majority of cells the neuraxon acquires a sheath to be thus converted into a medullated nerve-fiber. Thus, there are two kinds of nerve-fibers: *medullated,* or those with myelin; and *nonmedullated,* or those without myelin.

Medullated Fibers in the fresh condition are bright, glistening cylinders showing a dark, double contour. The essential part of the fiber is the *axis-cylinder.* This is a soft, transparent rod, or thread, which runs from one end of the fiber to the other. It does not anastomose with its neighbors, and in the average nerve is about $^1/_{1200}$ inch in diameter. After the employment of certain reagents the axis-cylinder shows itself to be composed of very fine, homogeneous or more or less beaded fibrillæ. The latter are the *elementary,* or *primitive fibrillæ.* They are held together by a small amount of a faintly granular, interstitial substance. The thickness of the axis-cylinder is in direct proportion to the thickness of the whole nerve-fiber. The axis-cylinder is enveloped in its own, more or less elastic, hyaline sheath.

The axis-cylinder is not regularly cylindrical, but is slightly narrowed in places. Under the influence of silver nitrate applied to its surface there appear alternate obscure and clear transverse striæ. They are the so-called lines of Frommann.

Myelin.—Surrounding the axis-cylinder is the myelin, *medullary sheath,* or the *white substance of Schwann.* It is a layer of fatty substance, strongly refracting, and of homogeneous aspect. It is colored black by osmic acid. It is the myelin which gives to the nerve its double contour. It is *composed* of a network of fibrils of a chemical substance called *neurokeratin,* which incloses the semi-fluid, fatty substance. The latter contains, among other substances, a complex, phosphorized fat.

The sheath of myelin envelops the axis-cylinder everywhere, except at its termination and at the nodes of Ranvier.

In its *arrangement* the myelin is imbricated in the fashion of tiles on a roof by reason of a series of segments one above the other. They are separated one from the other by clear lines. The lines are known as the *incisures* of *Lantermann,* and the *segments* as those of *Schmidt.*

Neurilemma.—The neurilemma or *sheath* of *Schwann,* surrounds the medullary sheath to form the outer boundary of the nerve-fiber. It is a thin, elastic, very delicate, hyaline, and transparent membrane. It is comparable to the cell-wall of a cell. Between the neurilemma and medullary sheath there are irregularly scattered ovoid nuclei. They are the *nerve-corpuscles,* and are analogous to the muscle-corpuscles previously mentioned. Each nerve-corpuscle is surrounded by a thin zone of protoplasm.

Between the myelin layer and the neurilemma is a thin zone of protoplasm. When this arrives at the level of the annular constrictions it is reflected upon itself to line the internal surface of the myelin layer (Mauthner's membrane). The protoplasm is also insinuated into the incisures of Lantermann and decomposes the layer of myelin into the superposed segments of Schmidt.

Nodes of Ranvier.—At intervals of about one micromillimeter along the course of the nerve there appear constrictions: the nodes of Ranvier. At these points the myelin sheath is interrupted so that the neurilemma appears to do the constricting. That portion of the nerve-fiber between any two constrictions is termed an *internodal segment.* At about the center of each internodal segment is located one, sometimes more, nerve-corpuscles.

Such is the composition of a medullated nerve-fiber. This type of nerve is found chiefly in the white matter of the nerve-centers and in the cerebro-spinal nerves, with the exception of the olfactory nerve.

NONMEDULLATED NERVE-FIBERS.—They occur especially in the sympathetic system, but are also present to a slight extent in the cerebro-spinal nerves.

Each fiber *consists* of a bundle of fibrils—*primitive fibrils*—which are inclosed in a delicate, transparent, and elastic sheath. The fibrils are very delicate and somewhat flattened. Here and there along the course of the fibrils will be found oval nuclei. These latter lie between the axis-cylinders and their enveloping neurilemma. As these fibrils contain no myelin, they are not blackened by osmic acid. This allows of a differentiation between medullated and nonmedullated nerves when examining the nerve-supply of a tissue.

NERVE-TRUNKS consist of bundles of nerve-fibers. Each bundle, of course, contains a greater or less number of fibrils. Several bundles are held together by a common connective-tissue sheath: the *epineurium.* Delicate fibrils lie between the nerve-fibers to constitute the *endoneurium*. The larger blood- and lymph- vesssls lie in the epineurium; the few capillaries of the nerve-fibers lie supported in the endoneurium.

Regeneration of United Nerves.—If a nerve is cut, its peripheral end undergoes degeneration. The fiber breaks up into small pieces of myelin, each holding a piece of neuraxon which is finally absorbed. Repair of the nerve begins wholly during the degeneration. The nuclei of the neurilemma increase in number to form around them a layer of protoplasm or cytoplasm. At length the cytoplasm becomes a continuous piece of protoplasm, and the fiber thus produced is known as a "band-fiber." Then there is an arrest of regeneration unless the peripheral fiber is anatomically united to its central connection. If the central and peripheral ends are brought together, then the "band-fiber" becomes changed into a normal nerve-fiber, with a sheet of myelin and a cylinder axis. The axis cylinder in the peripheral end of the nerve is supposed to grow out from the central end of the nerve.

Termination of the Nerve.—After a certain course in the trunk of the nerve the nerve-fiber divides at the periphery into a terminal plaque, the motor plaque of muscles; or into a sense-cell, as in the retinal cells or organ of Corti; or into a sense-corpuscle, as a tactile corpuscle; or into numerous fibrils which anastomose to form a terminal plexus, as in the cornea.

Nonmedullated Fibers, that is, those that are naked, pale or gray, and reduced to an axis-cylinder and sheath, branch and form networks—their peripheral terminations. This mode of termination occurs in the nerve-fibers of common sensation, as in many of the nerve-fibers of the skin, cornea, and mucous membrane. In all of these cases the peripheral termination fibrils are intra-epithelial: that is, they are situated in the epithelial portions of cornea, mucous membrane, etc.

Neuroglia.—In the gray, as well as in the white, substance of the nerve-centers there exists between the cells and nerve-fibers an intervening substance which has been termed neuroglia. It must not be confounded with the true connective tissue along the course of the blood-vessels in the nerve-centers. Its chemical nature is wholly different from the latter, which is always derived from the mesoblast. Ranvier has shown that neuroglia is derived from the primitive neuroblast or epiblast.

Neuroglia sometimes presents itself in the shape of very fine filaments assembled in a very close network, as in the gray substance.

Sometimes, again, it is seen under the aspect of reticulated plates bounding the space in which the nerve-fibers pass. This is beautifully demonstrated in the white substance of the columns of the spinal cord.

Elsewhere the neuroglia is found to be a homogeneous, gelatiniform substance, as in the ependyma of the spinal cord or in the gelatinous substance of Rolando in the postero-lateral groove of the same structure.

Besides the fibers and plates already mentioned, neuroglia contains cells. These are star-shaped, flat, and nucleated. They have numerous prolongations. By the aid of these prolongations the cells of the neuroglia anastomose freely with one another to form a very complicated network. This incloses in its meshes the nerve-elements.

Neuroglia enjoys the rôle of a true cement which unites all of the fibers and nerve-cells.

Classification of Nerve-cells.—According to Schäfer, nerve-cells are broadly classified into: "1. *Afferent cells,* which receive impressions at the periphery to convert them into impulses. The latter then pass toward the central nervous system. 2. *Efferent cells,* which send out nervous impressions toward the periphery. 3. *Intermediary cells,* which receive impressions from afferent cells to transmit them directly or indirectly to efferent cells. 4. *Distributing cells,* which occur near the periphery, and, receiving impulses from efferent cells, distribute them to involuntary muscles and secreting cells. The cells of this class belong to the so-called sympathetic system.

"The afferent and efferent cells are known as *root-cells.* The greater number of the nerve-cells of the brain and cord belong to the intermediate class. They serve the purposes of association and coördination and afford a physical basis for psychical phenomena." Efferent fibers are also called *cellulifugal.* Afferent fibers are also called cellulipetal.

Structure of the Gray Substance.—The gray matter is formed (1) of nerve-cells, (2) of neuroglia-cells, (3) of fibril elements representing the prolongations of nerve- and neuroglia- cells, (4) of an intervening network formed by the branching fibrils, and (5) of blood-vessels. Elements 1, 2, and 3 (here enumerated) of the structure have been treated previously in detail.

The blood-vessels penetrate the gray substance, and are surrounded with a layer of connective tissue coming from the pia mater, which they have received in their passage along and through this membrane. The connective tissue forms sheaths around the capillary network, arterioles, and little veins, in which the vessels seem to float.

These have been termed the *perivascular sheaths* of *His.* Between them and the vessels exists a lymph-space: one of the origins of the lymphatics.

White-substance Formation.—The white matter is formed by the bundles of white fibers covered by a lamellar investment of neuroglia. These bundles are separated from one another by tracts of connective tissue detached from the pia mater.

Axis-cylinders are also found, which come from the gray matter. Blood-vessels anastomose and run in a course parallel with the nerve-fibers. This circulatory network likewise has a perivascular sheath as has that in the gray substance.

Chemical Properties of Nervous Substance.—The following table of Landois gives the percentage of the various components of both gray and white matters:—

CHEMICAL COMPOSITION OF	GRAY MATTER.	WHITE MATTER.
Water	81.6 per cent.	68.4 per cent.
Solids	18 4 "	31.6 "
The solids consist of :—		
Proteids (globulins)	55.4 per cent.	24.7 per cent.
Lecithin	17.2 "	9.9 "
Cholesterin and fats	18.7 "	52.1 "
Cerebrin	0.5 "	9.5 "
Substances insoluble in ether	6.7 "	3.3 "
Salts	1.5 "	0.5 "

In 100 parts of *ash,* Breed found *potash, 32;* soda, 11; magnesia, 2; lime, 0.7; NaCl, 5; iron phosphate, 1.2; fixed phosphoric acid, 39; sulphuric acid, 0.1; and silicic acid, 0.4.

Composition of Nerve-tissue, According to Halliburton.—(*a*) Proteids. Over 50 per cent. in gray matter. They are:—

1. Neuro-globulin (alpha), coagulates at 47° C.
2. A nucleo-proteid which, like other proteids, causes extensive intravascular coagulation.
3. A neuro-globulin (beta).

(*b*) Nuclein from nuclei of cells.

(*c*) Neuro-keratin, from neuroglia.

(d) Phosphorized fats.

1. Lecithin; when decomposed it gives rise to glycero-phosphoric acid, stearic acid, and choline.

2. Protagon. Dr. W. J. Gies has shown that protagon is not a true body but a mixture of substances.
3. Kephalins.

(e) Cerebrins (nitrogenized substances, or
Cerebrosides. The name cerebrosides indicates that they are glucosides, and that the sugar (cerebrose) obtained from them has been identified as galactose.

(f) Cholesterin.

(g) Extractives: creatin, xanthin, hypoxanthin, inosite, lactic acid, uric acid, and urea.

(h) Gelatin.

(i) Inorganic salts, of which the alkaline phosphates and chlorides are the most abundant.

Haitai has shown that lecithin, when administered to white rats, caused a gain of 60 per cent. in body-weight compared with the normal animal. Hence lecithin is a stimulant of normal growth.

Reaction.—When passive, nerve-tissue is neutral or feebly alkaline. When active or dead it is said to be acid.

It is found that after death nerves have a more solid consistence. Probably some coagulation occurs which is to be compared to the stiffening of muscle. Simultaneously there is generated and liberated a free acid.

Mechanical Properties.—A remarkable property of nerve-fibers is the absence of elastic tension according to the varying positions of the body. Divided nerves do not retract.

The *cohesion* of a nerve is an important property. Oftentimes when a limb is forcibly torn from the body the nerve still remains intact (though considerably stretched), while the other soft tissues are completely severed. The sciatic nerve at the level of the popliteal space requires a force equal to one hundred and ten or one hundred and twelve pounds to rupture it; the median or ulnar require forces equal to forty or fifty pounds. The latter nerves will stretch six or eight inches before the point of rupture is reached. It is upon the knowledge of this fact that the method of nerve-stretching is employed in some forms of neuralgia.

Nerve-metabolism.—Some extractives are obtained which are believed to be decomposition products of the nerve.

The Nerve-centers.—The nerve-fibers and nerve-cells comprise the essentials from which the nerve-centers are formed; the elements must, of course, be held together by enveloping neuroglia. The term *center* is merely applied to an aggregation of nerve-cells which are so related to one another as to subserve a certain function. These cells give off numerous processes whereby they are brought into direct communication with one another as well as other parts of the body. These masses thus form structural integrations which perform corresponding integral functions. If at any time the structure suffers, the function must of necessity suffer also.

The nerve-centers comprise the spinal cord, medulla oblongata, pons Varolii, cerebrum, and cerebellum.

Common Properties.—There are certain properties which all nerve-centers seem to possess in common and which are of interest to the student:—

1. They all contain *nerve-cells.* These are the real centers of activity. They both originate and conduct impulses. Nerve-fibers are almost exclusively conductors.

2. Nerve-centers are capable of discharging *reflexes.* They are motor, secretory, and inhibitory reflexes.

3. They are the seat of *automatic excitement* when phenomena are manifested without the application of any *apparent* external stimulus.

4. The nerve-centers are *trophic centers* for both their nerves and the tissues supplied by them.

THE SPINAL CORD.

Structure of the Spinal Cord.

"The key to the study of the central nervous system is to remember that it begins as an involution of the epiblast. It is originally tubular with a central canal whose brain-end is dilated into ventricles. In the spinal cord there are three concentrated parts: First, the columnar, ciliated epithelium; outside of this is the central gray tube; and, covering all, the outer white, conducting fibers." (Hill.)

The spinal cord is that portion of the cerebrospinal axis which is inclosed within the vertebral canal. It extends in the form of a large, cylindrical cord from the upper level of the atlas to the first or second lumbar vertebra. Above it is continuous with the medulla oblongata. Below it becomes conical, to terminate finally in a slender filament: the *filum terminale.* It is attached to the base of the coccyx. The filum terminale emerges from the conical extremity of the spinal cord. The cone is a mass of nerve-roots which, from its striking resemblance to a horse's tail, has been termed the *cauda equina.*

The average length of the spinal cord is *eighteen inches.* In the fœtus the cord extends the whole length of the vertebral canal. The difference in relative length of the cord in the fœtus and in the adult is due to the unequal and more rapid growth of the spinal canal than of the cord. The cord thus *seems* to ascend in its canal. Instead of the spinal nerves of the lower portion of the cord leaving their points of emergence horizontally, they sweep down like the hairs in the tail of a horse to form the aforementioned cauda equina.

Coverings.—Not only is the cord protected by the spinal canal in which it is suspended, but in addition it is enveloped by a triple membranous container. The cord does not more than half fill the lumen of the spinal canal. It is suspended in this cavity surrounded by an aqueous medium: the *cerebro-spinal fluid.*

The investing membranes have been termed, from within outward, *pia mater, arachnoid,* and *dura mater.* They form a sheath, or *theca,* which is considerably larger than the cord. It is separated from the bony wall of the spinal canal by venous plexuses and loose areolar tissue.

The *pia mater* is a very delicate covering which is closely adherent to the cord. It sends numerous septa into the substance of the cord as well as into its anterior and posterior median fissures. It is composed of blood-vessels and connective tissue.

The *arachnoid* (spider's web) is, as its name implies, a very delicate, reticular membrane. It is nonvascular. Hanging like a curtain between the innermost and outermost membranes, it forms two spaces which are termed *subdural* and *subarachnoid.*

The outermost and toughest membrane is the *dura mater.* It is a very dense sheath and lies indirectly in contact with the canal-wall. However, unlike the dura of the brain, it does *not* form the periosteum for the portions of the vertebræ constituting the walls of the spinal canal.

Diameter of the Cord.—The volume of the cord is not the same throughout its whole extent. Although of a mean diameter of *half an inch,* yet it presents two decided enlargements.

The one enlargement is at the level of the inferior portion of the cervical region; the other at the lower portion of the dorsal region. The first one is the cervical enlargement from which emerge the nerves of the upper extremity. The name *brachial enlargement* has been given to it.

From the lower enlargement arise the nerves which proceed to the lower extremities. It is known as the *lumbar enlargement.* At the site of each enlargement the cord loses its cylindrical form to become somewhat flattened from before backward.

The formation of the enlargements is in intimate relation with the development of the members. In fishes we have only rudimentary members, the cord is of uniform diameter throughout. In steelworkers the cervical swelling is considerable.

The *weight* of the cord is about *one and one-fourth ounces;* it is equal to about *one fortieth* of the weight of the brain.

The *suspension* of the spinal cord within the canal is maintained laterally by irregular fibrous tracts which form the *ligamentum denticulatum.* Laterally the roots of the spinal cord give support; below, the filum terminale fastens it to the coccyx; above, its continuation as the medulla furnishes the most important support.

Exterior Form of the Cord.—Externally the cord has two longitudinal median grooves: one anterior, the other posterior. They traverse the entire length of the cord to divide it into two halves which are usually perfectly symmetrical. The origins of the spinal nerves are situated upon each side of these two parallel, longitudinal lines.

The *anterior median groove* divides the anterior surface of the cord into two perfectly equal parts. It extends from the decussation of the pyramids to the caudal extremity of the cord. In depth it occupies nearly a third of the thickness of this organ. In this groove is folded a layer of pia mater; at its base is seen a layer which passes from one-half of the cord to the other—the *white,* or *anterior, commissure.*

The *posterior median fissure,* deeper and narrower than the anterior, extends from the nib of the calamus scriptorius to the termination of the spinal cord. Into this groove the pia mater sends but a simple partition; but it is very adherent to the walls of the groove. The depth of the fissure is bounded by a commissure analogous to that which is furnished to the anterior median groove, but of a gray color. This is the *gray,* or *posterior, commissure.*

Upon each side of the cord are seen two lateral grooves which represent the lines of implantation of the anterior and posterior roots. They are known as the *antero-* and *postero-lateral grooves.* The latter is the more apparent of the two, showing itself in the form of a dotted, longitudinal line.

The antero-lateral groove corresponds to the line of insertion of the anterior roots of the spinal nerves. The two lateral grooves may be regarded as purely artificial; seen only after the spinal nerves are torn from the cord.

By virtue of the median and lateral fissures the cord is divided into columns, paired and symmetrical. The portion comprised between the anterior median and the antero-lateral fissures is known as the *anterior column.* That portion between the two lateral fissures bears the name of *lateral column.* That part between the postero-lateral and posterior median groove is the *posterior column.*

Anatomy and physiology demonstrate that the separation of the anterior from the lateral column is not complete; hence it is customary to reunite these two columns under the name of antero-lateral columns.

Internal Conformation of the Spinal Cord.—The texture of the cord is best studied by means of transverse section. These sections show that the cord is composed throughout its whole extent of two substances: one, the *cortical, white substance;* and the other, the *central, gray substance.*

The *white* substance is located peripherally and covers all of the gray substance except at the base of the posterior median groove. It forms the columns which have just been pointed out.

The *gray* substance forms in each half of the cord a longitudinal column whose transverse section appears in the form of a crescent with its concavity directed externally. The crescent terminates in two swollen extremities, the anterior one having the name of *anterior horn;* the posterior one, that of the *posterior horn.*

The two crescents are bound to one another at their convexity by the aid of a transverse band of gray substance, the gray commissure. This band is pierced centrally by a canal, the *central canal of the cord.* It runs down the central axis of the cord and is accompanied on each side by a vein, the *central veins of the cord.* In all sections the gray matter is vaguely represented by the letter H; perhaps better by the two wings of a butterfly united by a transverse bar. The column of gray matter is not exactly of the same form in its whole length. It is thicker in the cervical and lumbar regions than in the thoracic. The white matter is likewise thicker at the level of the cervico-dorsal and lumbar enlargements. At the level of the cauda equina the white substance forms but an enveloping layer for the gray matter.

In the cervical and lumbar regions the anterior cornua are remarkable for their volume; toward the dorso-lumbar enlargements the posterior cornua increase in size. The anterior cornu of the crescent is swollen. The posterior is more slender and reaches to the surface of the cord. Each cornu possesses a swelling (head) and a somewhat restricted portion (cervix).

The head of the posterior cornu is remarkable in that it is capped with a layer of neuroglia to which has been given the name of *gelatinous substance of Rolando.* It is nearly amorphous, and, in section, gives an appearance very similar to the small letter u. The substantia contains a few neuroglia cells, with some fusiform nerve-cells along its margin.

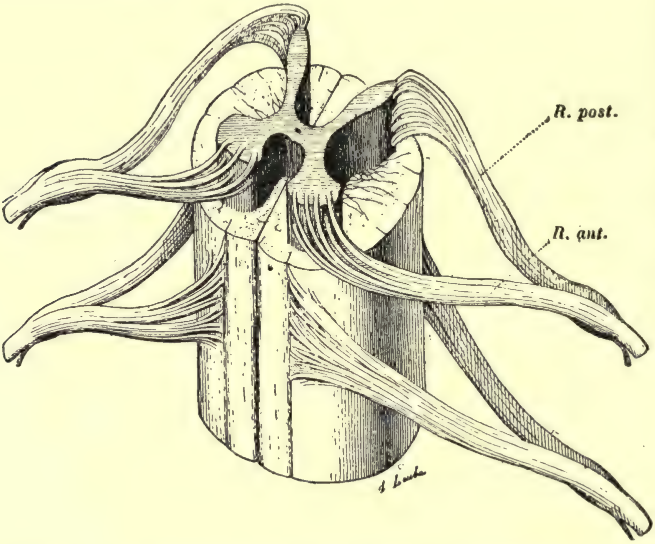


Fig. 236.—Two Nerve-pairs at Their Origin in the Spinal Cord—Anterior and Posterior Roots. (Morat.)

As regards the upper pair the figure shows the relation of the roots with the gray axis. In the lower pair is seen the emergence of the anterior roots at the surface of cord.

In the inferior cervical and superior thoracic region the most lateral portion of the anterior cornu is shaped in a special fashion so as to constitute a particular prolongation. This is known as the lateral cornu, or *intermedio-lateral column.* The cells of this column are arranged in groups of from eight to twelve bipolar cells whose long axes are vertical or more or less oblique. It is believed that these give origin to those fine medullated fibers which form the splanchnic efferent fibers.

On examination of sections it is seen that the anterior cornua do not reach to the surface of the cord. Hence that portion of the white substance which surrounds the anterior cornua reaches from the anterior median groove to the posterior cornua. It seems to form a homogeneous column: the *antero-lateral column.*

In the rear, on the contrary, the posterior cornua sharply separate the preceding to form *posterior columns.* They lie between the posterior median groove and the posterior cornua. In the cervical region the posterior column is sharply divided into two secondary columns by the posterior intermediate groove. These are the *columns* of *Goll* (next to the posterior median groove) and *Burdach* (in apposition with the posterior cornu).

From measurements by Stilling it seems that the cervical swelling results from a localization of superdevelopment of both gray and white matter of the cord. The lumbar enlargement is almost exclusively formed by a localized superdevelopment of gray substance. This is readily explained by the constitution of the columns themselves. Excepting the fibers forming the roots of the spinal nerves, the columns of white matter are formed of *descending,* or *motor,* and *ascending,* or *sensory, fibers.* The motor bundle successively gives off fibers to the motor roots of the spinal nerves to such a degree that in their descent their volume proportionately diminishes.

The sensory, or ascending, bundle, receiving fibers from each posterior root which comes from a sensory nerve, enlarges as it ascends. Hence it results that at the level of the lumbar enlargement the bundles are at a minimum, the ascending bundle just commencing, while the descending bundle is nearly spent.

Minute Constitution of the Cord.—The spinal cord is composed of fibers, nerve-cells, neuroglia, and blood-vessels. In the white substance there are found only nerve-fibers and neuroglia; in the gray substance, nerve-cells and fibers plunged in a stroma of neuroglia.

WHITE SUBSTANCE.—The white matter is composed principally of *medullated fibers* without the sheath of Schwann. The fibers in the white substance are, for the most part, arranged longitudinally; those which pass to the nerve-roots, as well as those fibers which proceed from the gray matter into the columns, possess an oblique course. In addition there are decussating fibers in the white commissure.

On cross-section the fibers (which are of different sizes) present the appearance of small circles with a rounded dark spot in their centers. This latter represents the axis cylinder of the fiber.

The diameter of the fibers varies from $^1/_{5000}$ to $^1/_{1200}$ inch. The most voluminous are the motor parts of the antero-lateral column and direct cerebellar tract; the finest are in the posterior median column.

Classification.—The fibers of the cord are classified into two great classes: *intrinsic* and *extrinsic.*

Intrinsic.—This class of fibers originates in and terminates in the cord, thereby uniting the levels of gray matter. Fixed by their lower extremities upon a given point of gray substance, they follow an ascending course, to become lost by their extremities in a more or less elevated part of the gray column. Thus they are fibers of union or association for the purpose of establishing communication between the different levels of the gray substance of the cord.

Extrinsic.—These fibers in the gray matter proceed to the ganglia of the brain after having traversed the medulla oblongata, pons, and crura. They unite the cells of the gray substance of the spinal cord to the upper nerve-centers. They are long and gradually diminish in number from the top to the bottom of the cord.

Degeneration occupies their whole extent. Some are *centripetal* and undergo an ascending degeneration. They are contained in the column of Goll, the direct cerebellar bundle, and Gowers's tract. The others are *centrifugal* fibers, and undergo a descending degeneration. They are localized in the crossed pyramidal and bundle of Türck. They are the last ones to appear in the fœtus.

The roots of the nerves arrive at the central gray substance and plunge into it after having passed between the fibers of the peripheral white substance. But few of them take part in the constitution of the cortical white matter.

Neuroglia.—In addition to the fibers just discussed the white matter of the cord contains neuroglia. From the neuroglia project extremely fine prolongations. These penetrate the cord to form within its thickness an infinity of partitions of extreme thinness. These are united to the adventitious tissue of the vessels and to the tissue which serves as a basement membrane to the epithelium of the ependyma. Thus there is formed (on transverse section) a polygonal network which isolates little colonies of nerve-elements one from the other. This sort of framework has been compared to a sponge in whose interstices are found the fibers and cells of the cord.

Neuroglia does not belong to the category of connective tissues. It is a special formation which is derived from the primitive epiblast. In the central gray substance the neuroglia does not seem to be any more than amorphous matter with some few cellular elements. The gelatinous substance of Rolando is composed of abundant neuroglia in the form of amorphous matter. The only connective tissue present in the cord is carried in by the blood-vessels.

GRAY MATTER OF THE CORD.—The gray substance of the cord is composed of *neuroglia, fibrils,* and *nerve-cells.*

The *cells* of the cord are formed by a small mass of protoplasm in which is plunged a nucleus surrounded by pigment-granules. These cells, whose volume varies with the groups, have a certain number of prolongations.

Cell-arrangement.—The cells of the cord are not disseminated in the gray substance in a disorderly way. They are grouped at certain points to form nuclei—nuclei of nerves; these are situated one above the other in a fashion to form columns parallel with the long axis of the cord.

There are distinguished three groups in the *anterior horns:* an *interior internal group,* an *anterior external group,* and a *posterior external group.*

In the *posterior horns* the cells are fewer in number; it is only at the internal part of the neck of these horns that there is found a grouping. It is known as the *dorsal nucleus* of Stilling or the *vesicular column* of Clarke.

The ganglionic cells of the anterior horns are very large, star-shaped, and from $^1/_{350}$ to $^1/_{200}$ inch in diameter. That is, they are nearly large enough to be visible to the naked eye.

Degeneration.—The nuclei of origin of the anterior roots are seized with degeneration in the various forms of muscular atrophy. The cells, by reason of their function, are known as *motor cells.* They are motors for the muscles to which their nerves go, and trophic for the same nerves and muscles. Progressive muscular atrophy is anatomically characterized by a general atrophy of the motor cells of the anterior horns of the cord. Children's palsy is also characterized by atrophy of these cells.

The cells of the posterior horns, irregularly distributed in the neuroglia, are fewer in number and smaller in size than are those of the anterior horns. Their diameters average about $^1/_{1200}$ inch.

Anatomically, the column of Clarke exists only from the second lumbar to the eighth dorsal pair of nerves. However, there are small, erratic groups of cells and two restiform nuclei at the level of the medulla which are analogous to the two columns of Clarke. The cells of the column of Clarke are very large, star-shaped, and only very meagerly branched.

The *intermedio-lateral gray column* is in the outermost portion of gray matter, midway between the anterior and posterior horns. It lies in what is known as the lateral horn. It is the *spinal origin* of the *great sympathetic.* A part of the posterior root-fibers are said to end in these columns. From this as a source fibers pass into the column of Goll and the direct cerebellar tract; others pass into the columns of Burdach and Gowers.

To the degenerative changes within the cells of the column of Clarke have been attributed the vasomotor troubles of paralysis agitans. Sclerosis of the lateral columns explains the exaggerated trembling in the reflexes.

The fibers of the cells of the gray matter form a spongy substance which unites the two halves of the gray axis of the cord to one another. This, the *gray commissure,* passes in front of and behind the central canal of the cord.

Neuroglia.—The neuroglia of the gray matter has a structure analogous to that of the neuroglia of the white substance of the cord. It is found in particular abundance at the extremity of the posterior horns (gelatinous substance of Rolando) and at the periphery of the central canal.

The Central Canal.—This is a canal of very fine caliber located within the center of the gray commissure. It transverses the entire length of the cord, and, at the level of the nib of the calamus scriptorius, is continuous with the fourth ventricle; by means of the latter it communicates with the ventricles of the brain.

The *wall* of this canal, known as the *ependyma,* is composed—from within outward—of: (1) a ciliated epithelium, (2) an amorphous basal membrane, and (3) a substratum of neuroglia which unites the wall of the canal to the body of the cord. The canal is flanked on each side by a *longitudinal vein;* the two constitute the *central veins.*

Systemization in the Spinal Cord.—The spinal cord may be considered as formed of a series of segments superposed. They are metameres corresponding to each pair of spinal nerves. Each one of these is a complete center, being supplied with nerve-cells and motor and sensory nerves. Each one is different from its neighbor, since it innervates a particular area of the surface of the body, whether it be tactile surface or muscular group.

The nerve-cells are grouped in motor and sensory fields. They are all in perfect communication with one another by reason of numerous fibers; some are longitudinal (*longitudinal commissures*) which unite the various levels of the cord; others are transverse

(*transverse commissures*) whose function seems to be to unite the cells of the right side to those of the left side of each segment. The transverse commissures are but from one to three centimeters in extent.

In addition to the spinal commissures just mentioned there are two other kinds formed by the long fibers uniting the spinal cord either to the cerebrum or cerebellum. They are known as the *cerebro-spinal* and *cerebello-spinal fibers.*

Experimental physiology, pathological anatomy, and embryology all agree very admirably in demonstrating that the apparently homogeneous cord is composed of distinct and specialized parts. These parts are called systems, which, in the white substance, form secondary columns, or bundles.

White Columns of the Cord.

Flechsig ascertained that in the fœtus the different bundles of nerve-fibers did not all take on myelin layers at the same time. By taking advantage of this fact he was able to trace the bundles of fibers with myelin and thus map out the different tracts of the spinal cord and brain. Gudden extirpated an organ of sense and after waiting a sufficient length of time was able to trace the course of the atrophied nerve-fibers.

The nerve-fibers of the cord enveloping the central gray axis are distributed in different bundles or columns. These have previously been mentioned cursorily, but will now be discussed in detail.

Anterior Column.—The anterior column comprises that area between the anterior median groove and the line of implantation of the anterior roots of the spinal nerves. Its most internal fibers are commissural; they cross throughout the whole extent of the cord and so contribute in the formation of the white commissure. Other fibers run across at the same level to connect the large cells of the anterior horns of the two halves of the spinal cord.

The anterior column comprehends two bundles: one, internal (next to the median groove), is known as *Türck's bundle,* or *direct pyramidal bundle;* the other, external, comprises the remainder of the anterior column and is known as the *root-bundle* of the *anterior column,* or *antero-lateral ground-bundle.*

The bundle of Türck (pyramidal bundle, direct cerebral, direct motor) is formed of centrifugal fibers which descend from the brain into the cord without decussating at the level of the medulla oblongata. Its fibers are longitudinal and travel along and through the brain, the anterior pyramid of the medulla and the same side of the corresponding half of the spinal cord. Yet, having arrived in the cord, *some* of its fibers *cross* to the opposite side along the path of the white commissure. They finally terminate in the cells of the anterior cornua. This bundle usually terminates about the second lumbar nerve. It undergoes descending degeneration.

The *antero-lateral ground-bundle* (root-bundle of the anterior column) occupies the territory between the preceding and the antero-lateral groove. It is formed in part by the anterior roots which descend in a certain course within its interior; but especially by the more or less long, longitudinal fibers. The latter unite between themselves the successive levels of the anterior horns. It is thus in part a system of longitudinal commissural fibers.

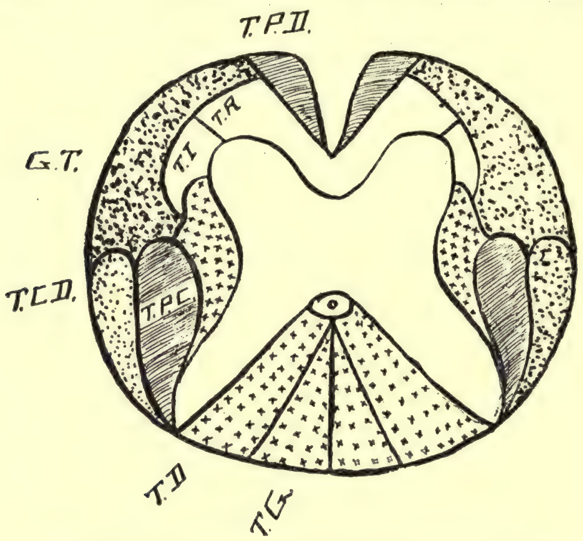


Fig. 237.—Transverse Section of the Spinal Cord.

T. D., Burdach's tract. *T. G.*, Goll's tract. *T. P. C.*, Crossed pyramidal tract. *T. C. D.*, Direct cerebellar tract. *G. T.*, Gower's tract. *T. P. D.*, Direct pyramidal tract, or Türck's. *T. L. P.*, Deep lateral tract. Straight lines are motor tracts. Little crosses are sensory tracts. Dotted spaces are cerebellar tracts. *T. I.*, *T. R.*, Root tracts.

The anterior ground-bundle is continued beneath the floor of the fourth ventricle in the superior longitudinal bundle, and ends in the gray matter of the third ventricle, giving off collaterals to the nuclei of the oculo-motor, pathetic, and abducent.

Lateral Column.—The lateral column is bounded between the line of implantation of the anterior roots and the line of insertion of the posterior roots. It is formed of fibers which are larger on the surface and much finer in the depths.

This column comprises *five different* systems of bundles. They are: (1) the *direct cerebellar;* (2) the bundle of *Gowers,* or *ascending antero-lateral-cerebellar tract;* (3) the *crossed pyramidal tract;* (4) *vestibulo-spinal tract;* (5) *deep lateral,* or *lateral marginal, zone.*

The *direct cerebellar bundle,* or *tract,* is situated at the posterior and superficial part of the lateral column in the form of a very thin band. It extends from the second lumbar upward to the restiform bodies, into the vermis of the cerebellum. It is formed of a collection of centripetal fibers which unite the cerebellum to different levels of the vesicular column of Clarke. It develops ascending degeneration. About the cells of Clarke arborize the collaterals of the posterior root so that there is an indirect communication between the posterior roots and the cerebellum.

The *bundle of Gowers,* or ascending antero-lateral tract, occupies the anterior superficial zone of the lateral column. This bundle commences at its inferior part in the lumbar swelling, increasing in size as it ascends by two orders of roots, some fine, others large. It terminates by its fine fibers in the lateral nucleus of the medulla; by its larger fibers in the cerebellum by way of the superior peduncle. This tract undergoes ascending degeneration.

The *crossed pyramidal tract* (motor tract or cerebral crossed tract) is situated inside the cerebellar tract. The term has been applied to that which is contained within the pyramids of the medulla, and which decussates at this level with the opposite tract. It decreases in volume from above downward to terminate in from the second to the fourth lumbar pair.

It is composed of long, centrifugal fibers which unite the motor regions of the cortex of the brain with the motor cells of the anterior horns of the cord. It undergoes descending degeneration as the result of lesions which seize the cortex, internal capsule, or cerebral peduncle.

A lesion of the pyramidal tract in the cord produces monoplegia below the lesion and on the same side. Its degeneration, as a result of lesion of the brain, gives place to a crossed hemiplegia, whose clinical mark is a spasmodic contracture.

It is well to remember that there is a double decussation of the motor fibers: one at the level of the neck of the medulla oblongata, the other much lower—the length of the white commissure. From this the student can comprehend why in the majority of hemiplegias the non-paralyzed member has, nevertheless, lost its muscular energy; also why a unilateral cerebral lesion is able to cause permanent contracture of the two inferior members or an exaggeration of the reflexes of the side not paralyzed.

The vestibulo-spinal tract runs from the vestibular nucleus, which contains Deiters's nucleus, and descends in the antero-lateral columns, arborizing about the anterior horns. This tract is connected with the nucleus fastigii of the cerebellum.

The *deep lateral tract*, lateral mixed tract, or lateral marginal zone, is molded upon the lateral concavity of the gray matter. It incloses at the same time the fibers coming from the anterior motor horns, the gray column of Clarke, and the gray intermedio-lateral column.

The lateral ground-bundle is continued in the posterior longitudinal bundle and ends in the posterior corpora quadrigemina. The posterior longitudinal bundle puts the sensory bulbar nuclei and the tubercula quadrigemina in communication with the nuclei of the motor nerves of the eyes and the motor nerves of the trunk.

Posterior Columns.—The posterior columns comprise that area of the spinal cord lying between the postero-lateral groove and the posterior median groove. It is composed of fine fibers in that portion nearest the median groove, and is remarkable for its abundance of neuroglia.

This large tract is divided into two tracts: one *internal*, the other *external*.

The *internal* one, or column of Goll, is especially apparent in the upper part of the cord. Here it occurs in the form of a triangular pyramid whose base is turned toward the central gray commissure. It is formed by long commissural fibers which arch so as to unite the posterior horns. It proceeds from the level of one posterior horn to that of a higher level. It incloses the posterior root-fibers which compose the major portion of it. The fibers of Goll are very long, ascending from the cauda equina to Goll's or gracilis nucleus of this tract in the medulla. Its trophic centers are in the cells of the ganglion of the posterior root.

The more external and cuneiform tract, *column of Burdach*, contains *short, commissural, longitudinal fibers* which have the same distribution as those of Goll, and *sensory fibers*, which also spring from the posterior horns, but do not sojourn there. Almost immediately they pass into the mixed lateral column of the same side, or, traversing the commissure, cross into the opposite tract. At the level of the medulla oblongata these fibers go to form the *lemniscus*, or *fillet*, which itself terminates in the corpora quadrigemina, the optic thalami, and the sensory convolutions. In transverse section of this column there is ascending degeneration.

The *comma tract* is composed of a few fibers in the column of Burdach. After lesions of the cord they undergo descending degeneration. These fibers originate from the descending fibers of the posterior roots.

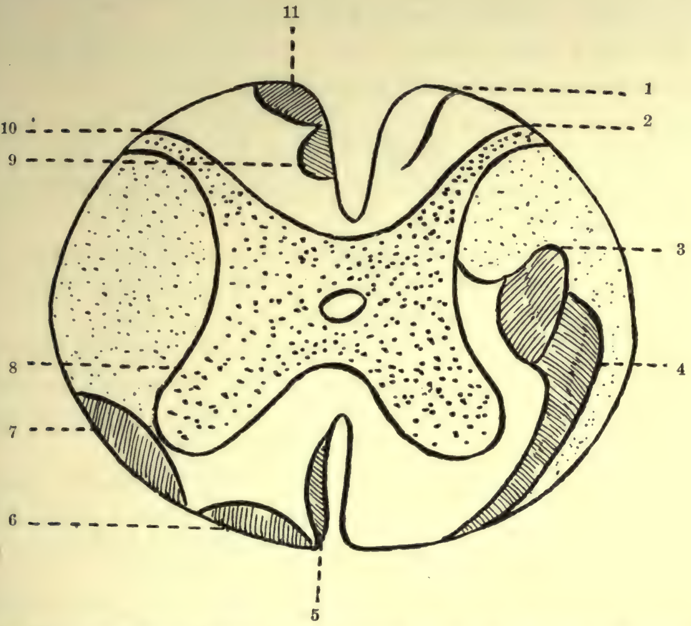


Fig. 238.—Section of Spinal Cord, Showing the Less Well-known Tracts.

1, Comma tract. 2, Lissauer's tract. 3, Monakow's prepyramidal or rubrospinal tract from nucleus ruber down lateral column to anterior horn. 4, Vestibulo-spinal tract from vestibular nucleus down to anterior horn. 5, Sulcomarginal tract from corpora quad. 6, Anterior marginal bundle from nucleus fastigii. 7, Helweg's bundle from olivary body. 8, Anterior root. 10, Posterior root. 9, Oval bundle. 11, Septo-marginal.

The posterior columns, and particularly the columns of Burdach, are the seat of the sclerosis known as *tabes dorsalis*, or *locomotor ataxia*. Clinically this disease is characterized by progressive abolition of co-ordination, loss of equilibrium, paralysis of eye-muscles, loss of tendon reflexes, etc.

Tracts of Lissauer.—About the entrance of the posterior roots into the postero-lateral groove of the cord are found two small, cuneiform columns. They are the *root-zones* of *Lissauer.* The one is internal, the other external. The two zones are formed by the posterior root-fibers at their entrance into the cord. They have the same properties as the posterior roots and undergo ascending degeneration under the same conditions that produce it in the latter.

Degeneration.

Descending Degeneration.—The crossed pyramidal, the direct pyramidal, the vestibulo-spinal, the comma tract.

Ascending Degeneration.—Goll's, Burdach's, Gowers' (ascending antero-lateral cerebellar), direct cerebellar, Lissauer's tract.

Roots of Nerves.

The spinal nerves, thirty-one pairs in number, exist throughout the entire length of the cord.

The *anterior root-fibers* are composed of large nerve-tubes which lose themselves, for the most part, in the ganglionic cells of the *anterior horns* of the same or opposite sides.

The *posterior root-fibers* are composed of fine tubes. After having arisen in the intervertebral ganglia they go toward the postero-lateral groove, where they enter the cord. There are here two groups of fibers: one external, the other internal.

The *external root-fibers* penetrate into the gelatinous substance of Rolando, where they become ascending. After a more or less lengthy course they pass into the ganglionic cells of the posterior horn.

The *internal root-fibers,* which pass into the posterior column, become lost either in the cells of the posterior horn or in the vesicular column of Clarke. Some very long fibers ascend to the nuclei of Goll and Burdach in the medulla, where they terminate.

Some of the fibers traverse the posterior commissure to pass either into the anterior horn of the opposite side (and act in reflex motor actions) or into the posterior horn or descend in the cord as fibers of the comma tract.

Commissures of the Cord.

The *white, anterior commissure* is formed by a body of fibers which decussate upon the median line to pass into the lateral half of the cord opposite to that from which they came. It forms the major portion of the fibers of the direct pyramidal tract. This tract in its long course in the cord gives off fibers in succession which go either into the cells of the anterior horn or into the crossed pyramidal tract of the opposite side. The commissure also contains fibers which unite transversely the anterior horns of the two sides.

The *gray*, or *posterior, commissure* is likewise formed by decussations upon the median line both in front of and back of the central canal. The fibers comprising this decussation are: some of the fibers from the posterior roots on one side to terminate in the opposite posterior horn; also, fibers of the posterior horn which go into the deep lateral tract.

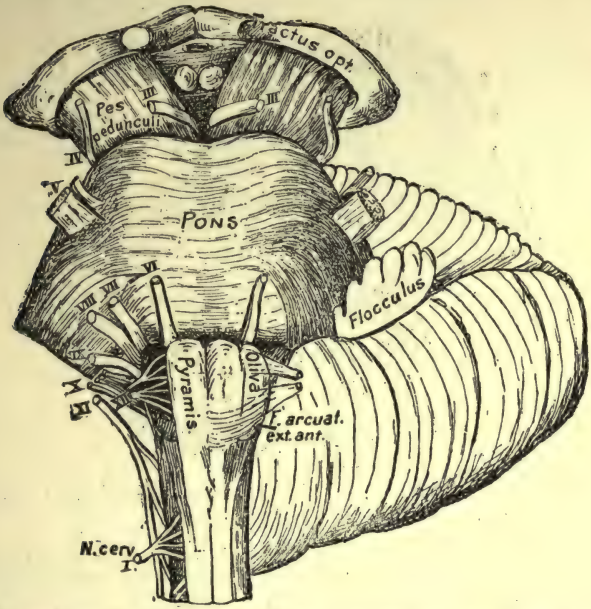


Fig. 239.—Medulla Oblongata, Pons, Cerebellum, and Pes Pedunculi. Anterior View, to Demonstrate Exits of Cranial Nerves. (EDINGER.)

Medulla Oblongata.

The medulla oblongata is a continuation of the spinal cord which crowns its upper part in the form of a capital. It reaches from the cord to the pons Varolii. The medulla is an enlargement in the form of a truncated cone, a little flattened from before backward. It measures an inch in length, about three-fourths in width, and about one-half inch in thickness. Commencing toward the middle part of the odontoid process, it inclines forward, to recline upon the basilar process of the occipital bone. The medulla forms with the cord an obtuse angle open in front.

The back and sides of the medulla are embraced by the cerebellum. In front, the medulla is bounded anteriorly by the pons Varolii, posteriorly by a transverse line which unites the lateral angles of the fourth ventricle to divide its floor into two triangles.

The anterior and posterior median fissures of the cord are continued up into the medulla. The anterior fissure becomes somewhat indistinct at one point by reason of the decussation of the bundles forming the pyramids. The posterior median fissure terminates at the lower end of the fourth ventricle. The weight of the medulla is about *one hundred grains.*

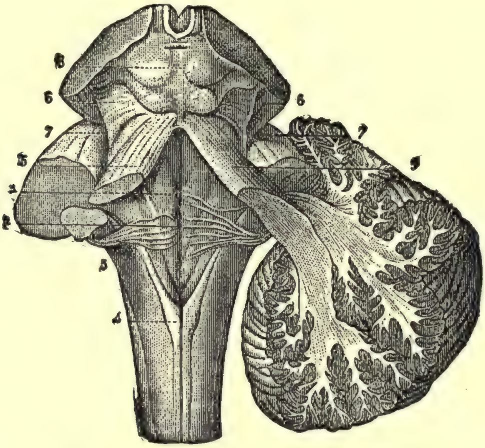


Fig. 240.—The Three Pairs of Cerebellar Peduncles. (After Hirschfeld and Leveillé.)

1, Fossa rhomboidalis. 2, Striæ acusticæ. 3, Posterior cerebellar peduncle. 5, Anterior cerebellar peduncle. 6, Fillet. 7, Middle cerebellar peduncle, or Brachium pontis. 8, Corpora quadrigemina.

From the front and sides of the medulla arise the sixth to the twelfth cranial nerves, inclusive.

External Form of the Medulla Oblongata.—Inspection of the inferior surface of the medulla first brings to view along the median line the *anterior median groove.* This, as before mentioned, is a continuation of a similar groove belonging to the cord. In one area the crossing of the white fibers from side to side (decussation of the pyramids) renders this more shallow. At the base of the groove is seen a continuation of the white, anterior commissure of the cord. This layer unites the two pyramids of the medulla and is known as the *raphé* of *Stilling.*

ANTERIOR PYRAMIDS.—On each side of the median groove are located two white columns, which are slightly swollen at their upper ends and have the appearance of clubs. These columns are the *anterior pyramids.*

OLIVES.—Just outside of the upper portion of the pyramids are two prominent, oval masses whose longer axes are vertical. These bodies measure about one-half inch in length and one-fourth in breadth. They are the inferior olives. They are prominences added to the medulla, and do not have any similar portions in the spinal cord. The olives are separated from the pyramid in front by a groove; in this latter is embodied the continuation of the false antero-lateral groove. In it is found the apparent origin of the hypoglossal nerve. Behind, the olives are separated from the restiform bodies by another groove: a continuation of the postero-lateral groove of the spinal cord. From it emerge the glosso-pharyngeal, the vagus, and the spinal accessory. At their lower edge these grooves are somewhat effaced by the white arcuate fibers of the olive; these latter ascend in the restiform bodies.

RESTIFORM BODY.—Back of the postero-lateral groove of the medulla, and therefore on its posterior surface, is found a large column of white substance: the *restiform body.* It seems to be continuous below with the posterior columns of the cord; above with the inferior peduncle of the cerebellum. These columns form part of the anterior as well as lateral aspects of this organ.

Posteriorly it is seen that the inferior third of the medulla is very different from the upper two-thirds. The inferior third is similar to the cord in that it possesses a posterior median groove continuous with that of the cord; on each side of it are two white columns. They are continuations of the posterior columns of the cord.

At the base of the groove is found the gray commissure.

In the upper two-thirds of the medulla this form is much changed. Here the posterior columns take the name of restiform bodies, or inferior peduncles of the cerebellum. Instead of pursuing a parallel course, they diverge from one another in such a manner as to leave between them at their upper end a V-shaped surface. The surface included within this angular space comprises gray matter. It forms the lower half of the floor of the fourth ventricle. The upper, angular portion is formed by the posterior face of the pons.

The beginning of divergence of the restiform bodies presents

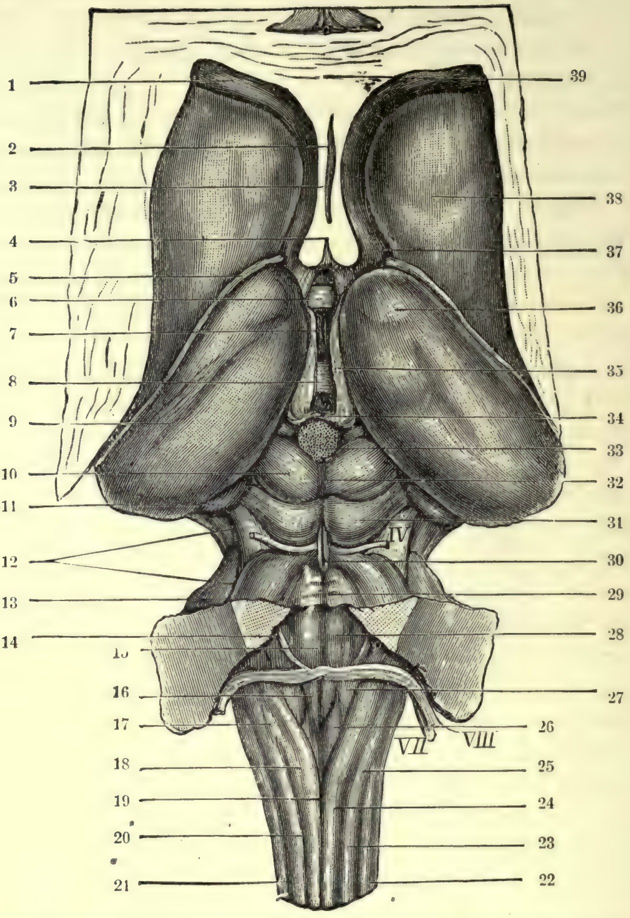


Fig. 241.—Metencephalon, Mesencephalon, and Thalamencephalon, from the Dorsal Surface. (GORDINIER, after OBERSTEINER.)

1, Anterior cornu of lateral ventricle. 2, Fifth ventricle. 3, Septum lucidum. 4, Anterior pillars of fornix. 5, Tænia semicircularis. 6, Anterior commissure. 7, Third ventricle. 8, Middle commissure. 9, Sulcus choroideus. 10, Nates. 11, Corpus geniculatum internum. 12, Lateral groove of mesencephalon. 13, Pons. 14, Conductor sonorus. 15, Sulcus longitudinalis medianus. 16, Trigonum hypoglossi. 17, Corpus restiforme. 18, Clava. 19, Posterior fissure. 20, Sulcus paramedianus dorsalis. 21, Sulcus lateralis dorsalis. 22, Lateral column. 23, Funiculus cuneatus. 24, Funiculus gracilis. 25, Tuberculum cuneatum. 26, Ala cinerea. 27, Tuberculum acusticum. 28, Eminentia teres. 29, Lingula. 30, Frenulum veli. 31, Testis. 32, Sulcus corp. quad. longitudinalis. 33, Pineal body. 34, Pedunculus conarii. 35, Stria pinealis. 36, Optic thalamus. 37, Foramen of Monro. 38, Caudate nucleus. 39, Corpus Callosum.

an appearance analogous to that of a writing pen; hence its name: *calamus scriptorius.* The space between the restiform bodies presents a median groove. Above it passes over the posterior face of the pons; below it is arrested by the point of divergence of the restiform bodies. This is known as the *groove of* the *calamus scriptorius.* From each side of this groove there proceed white transverse fibers whose direction is at right angles to that of the groove. They are known as the *barbæ* of the *calamus,* or *auditory striæ.* These fibers are the posterior roots of the auditory nerve.

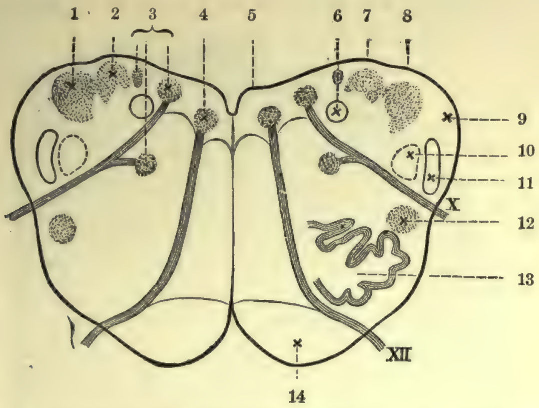


Fig. 242.—Diagrammatic Transverse Section of the Spinal Bulb × 3, at about the middle of the olivary body, to illustrate the principal nuclei and tracts at that level. (Waller, after Schwalbe.)

1, Nucleus cuneatus. 2, Nucleus gracilis. 3, Vagus nuclei. 4, Hypoglossal nucleus. 5, Funiculus teres. 6, Funiculus solitarius. 7, Funiculus gracilis. 8, Funiculus cuneatus. 9, Restiform tract. 10, Substantia gelat. Ro. 11, Spinal root of fifth nerve. 12, Antero-lateral nucleus. 13, Olivary body. 14, Anterior pyramid.

The restiform bodies, which seem to form the limits of the floor of the fourth ventricle on each side of the calamus scriptorius, come up from the posterior columns of the cord. They ascend upward and outward toward the cerebellum.

The columns of Goll and Burdach of the spinal cord as they enter the lower portion of the posterior aspect of the medulla seem to be divided into several distinct tracts. Bordering upon the posterior median fissure is the column of Goll. As the tract approaches the fourth ventricle it broadens out to form the expansion known as the *clava.* The two clavæ diverge to form the nib of the calamus scriptorius.

Lying external, but adjacent, to the column of Goll is another tract which is a continuation of the column of Burdach. It is the *funiculus cuneatus.*

As previously stated, the upper, expanded portion of the gracilis nucleus has been termed the clava; the upper portion of the cuneatus is known as the *cuneate tubercle.* Both prominences are caused by underlying masses of gray matter.

The scriptorial half of the floor of the fourth ventricle is divided into two lateral halves by a longitudinal groove. In each half can be seen three small prominences whose general shape is somewhat triangular. The first one, a triangle of white color, is the *trigonum hypoglossi;* it covers the nucleus of origin of the hypoglossus nerve. The second one, trigonum vagi and the continuation of the head of the anterior horn, corresponds to the nuclei of the ninth, tenth, and eleventh cranial nerves. It is the *ala cinerea.* The third eminence, the trigonum acustici, covers the nucleus of the eighth nerve.

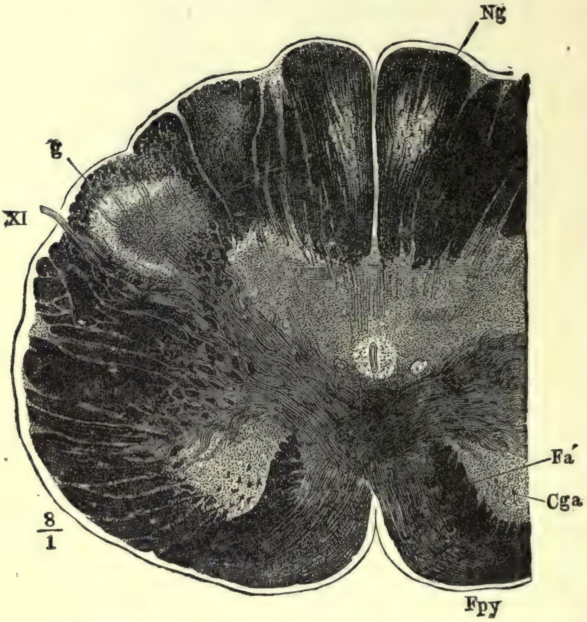


Fig. 243.—Cross-section of the Oblongata through the Decussation of the Pyramids. (After Henle.)

Fpy, Pyramidal tract. *Cga,* Anterior horn. *Fa',* Remnant of anterior column. *Ng,* Nucleus funiculi gracilis. *g,* Substantia gelatinosa. *XI,* Nervus accessorius.

Internal Structure of the Medulla.—The medulla oblongata, like the spinal cord, is formed of nerve-cells, nerve-fibers, and a meshwork of neuroglia. As it is a continuation of the cord, one ought to find the white columns and central axis common to the spinal cord. As a matter of fact, the constituent elements of the cord *are* found in the medulla, but their position is changed very much. The cells forming the nuclei of nerves are analogous to those of the cord, but are more isolated. They also give exit to fibrils which unite them to other cells in the opposite half of the medulla and in the brain proper, and to nerves of which they are the seat of origin. In the medulla the grouping of these nuclei is quite different to that found in the spinal cord. However, it is always the same central gray substance, but modified in its form and arrangement. The gray matter is cut here and there by white columns and their fragments.

To understand this new disposition of the gray matter it is necessary to recall that at the level of the medulla the central gray substance of the cord has been pushed backward by reason of several factors. These are: the separation of the restiform bodies, the passage outward of the posterior columns, and the formation of the rhomboid sinus. The latter is so arranged as to form the floor of the fourth ventricle. The posterior horns have become separated and are so rotated upon themselves as to be thrown outward and thus placed at the external part of the fourth ventricle. The anterior cornua have their bases placed upon the floor of the fourth ventricle on each side of the median raphé.

The isolated horn of gray matter is afterward known as the *nucleus lateralis.*

Further, the crossed pyramidal tracts of fibers are carried forward, outward, and upward. By the oblique passage of these numerous white fibers through the gray matter of the anterior horn the anterior horn is broken up so that the caput is entirely separated from the remainder of the gray matter. The fibers in passing through the base of the anterior horns to decussate upon the median line with those of the opposite side give rise to the reticulated formation of Deiters and to the raphé of Stilling.

Formatio Reticularis.—The formatio reticularis is an associated system of the short fibers with nerve-cells and is met with at any point between the spinal cord and the optic thalamus. These fibers run at right angles to one another. It is the result of the decussation of the crossed pyramidal and arciform fibers which, in their march forward and upward, travel through the base of the anterior horns in the form of a multitude of small bundles. These arch and decussate from side to side.

Still higher up the fillet decapitates, as it were, the posterior horns. The caput comes close to the surface, where it forms the distinct projection known as the gelatinous substance of Rolando. The cervix of the cornu becomes broken up in a manner similar to that of the anterior horn.

White Substance of the Medulla.—This is formed by the prolongation of the columns of the spinal cord and by additional white masses, the olives and arcuate fibers.

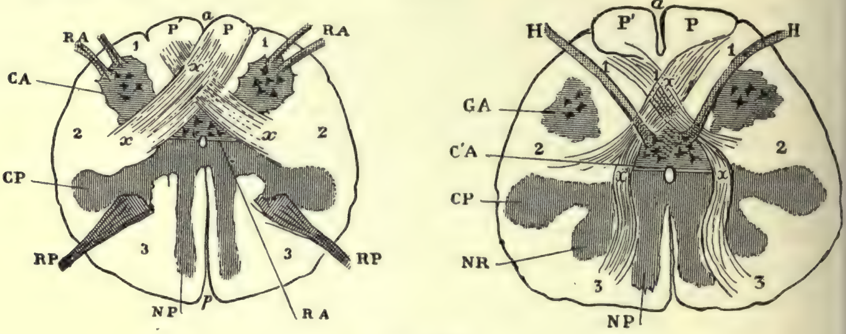


Fig. 244.

Section of Medulla Oblongata at the Level of the Decussation of the Pyramids—Motor Decussation. (M. Duval.)

1, 2, 3, Anterior, lateral and posterior columns. *CA*, *RA*, Anterior horns and roots. *CP*, *RP*, Posterior horns and roots. *RA*, Part of anterior horn whose head *CA* has been detached. *X*, Decussation of lateral columns at pyramids (*P*, *P'*). *NP*, Nucleus of posterior pyramids. *a* and *p*, Anterior and posterior median grooves.

Section of Medulla Oblongata at the Upper Part—Sensory or Fillet Decussation. (M. Duval.)

GA, Head of anterior horn. *C'A*, Base of anterior horn, nucleus of hypoglossal nerve. *H*, Root fiber of hypoglossal. 1, 2, 3, Anterior, lateral, and posterior columns. *x*, *x*, Fibers coming from the posterior columns and forming sensory or fillet decussation in *x*. *P*, *P'*, Pyramids. *NR*, Nucleus of restiform body. *NP*, Goll's nucleus. *CP*, Posterior horn.

White Columns.—The *direct pyramidal tract*, whose fibers decussate the length of the cord by traversing the white commissure, do not cross at the level of the medulla. They pass directly into this organ, to be placed in the anterior pyramid of the corresponding side. At the level of the medulla the two principal anterior columns, those of the right and left, which heretofore pursued a parallel course, now separate from the median line. They carry themselves outward and backward for a little distance, then bend inward to pursue a parallel course again. By this course there is formed a sort of elliptical buttonhole which is inclined obliquely from bottom to top. Traversing this buttonhole are found the crossed pyramidal bundles; both are carried toward the median line, where they decussate with the opposite side to produce the pyramidal decussation. Thus, the two principal bundles of the anterior columns have become posterior in the medulla, where they are placed in the deepest part of the pyramids.

Lateral Columns. — The crossed pyramidal bundle in the medulla bends toward the median line. Here it meets its fellow of the opposite side, with which it decussates in the manner of a twist to arrive in the opposite side of the medulla. At this level, in the same pyramid of the medulla, there exist side by side the direct pyramidal column of the same side of the cord and the crossed pyramidal bundle of the opposite side. These two bundles now form one and the same group of nerve-fibers. This type of fibers forms the pyramidal, or cerebral motor, tract. Along this course descend motor messages to the voluntary muscles from the brain to the anterior horns of the cord, and then along axis-cylinders to the motor plates in muscles.

An act incited by an impulse traveling along this course is always crossed, since the left hemisphere of the brain, for example, carries the order of motor power to the right half of the spinal cord by the crossed pyramidal fibers and to the left half of the spinal cord by the direct pyramidal tract. The latter tract decussates throughout the length of the cord with its fellow of the opposite side. Thus, the result is that the decussation is total for the pyramidal tract in its complete action, and that all of the voluntary parts excited from some part of the cerebral hemisphere end in muscles of the opposite side of the body. From this the student will deduce that lesions which affect the pyramidal tract above the medulla oblongata have as their direct result a motor paralysis opposite to the lesion; in other words, a crossed hemiplegia.

Posterior Columns. — The columns of Goll ascend to the medulla, where they pass, without decussation, into the postpyramidal nucleus, or nucleus of Goll. By this nucleus it is carried into the cerebellum, following part of the restiform body; another part is placed in relation with the nuclei of the pons.

The column of Burdach comprises the longitudinal commissural fibers, the root-fibers of the posterior roots, and the sensory fibers issuing from the column of Clarke. The root and commissural fibers pass, without decussation, into the cuneate nucleus, or nucleus of Burdach.

Parts added to the *medulla oblongata,* which are not found in the cord, are: *arcuate fibers* and *olives.*

Arcuate fibers are the curved fibers which are seen in transverse section of the medulla. By reason of their position they have been termed *superficial* and *deep,* or *external* and *internal.*

The *superficial arcuate* fibers form a more or less voluminous ribbon. They are fibers which come from the cells in Goll's and Burdach's nuclei. They proceed to the restiform body of the same side and thence to the cerebellum.

The *internal arcuate fibers* likewise proceed from the cells of the nuclei of Goll and Burdach. The hindmost fibers form the sensory decussation of the fillet. Other fibers cross the median raphé in the substance of the medulla, then to pass upward into the brain.

The *olivary body* is formed by a portion of the white cortical substance which belongs to the lateral column, and by the corpus dentatum, a layer of intervening gray matter folded upon itself, in such a manner as to represent an oblong purse. This is open at its internal aspect, and is known as the *hilus* of the olive. The corpus dentatum of the olive is formed by a great quantity of small, multipolar cells. The fibers which emanate from it go to the olive of the opposite side, traversing the raphé or mounting toward the pons.

Pons Varolii.

The pons is a mass of nervous tissue placed transversely and in the form of a half-ring. It is situated between the medulla oblongata and cerebral peduncles, which limit it below and above, respectively. The cerebellar hemispheres bound it laterally. Its weight is sixteen or seventeen grams.

For examination microscopically the pons presents six surfaces or faces.

1. The *anterior* face is free, convex, and rounded, and rests upon the basilar gutter of the occipital bone. It presents an antero-posterior median depression: the *basilar groove.* On each side of this are two parallel prominences due to the heaving up of the annular fibers by reason of the anterior pyramids which pass through it.

Upon this face are seen the transverse fibers which pass laterally to penetrate into the corresponding hemisphere of the cerebellum.

They thus form a large column upon each side, known as the *middle cerebellar peduncles.*

2. The *posterior* face forms part of the floor of the fourth ventricle, and is continuous with the corresponding face of the medulla oblongata. It forms a triangle whose apex, turned upward, is placed at the level of the lower orifice of the aqueduct of Sylvius. The sides of this triangle are formed by the superior cerebellar peduncles.

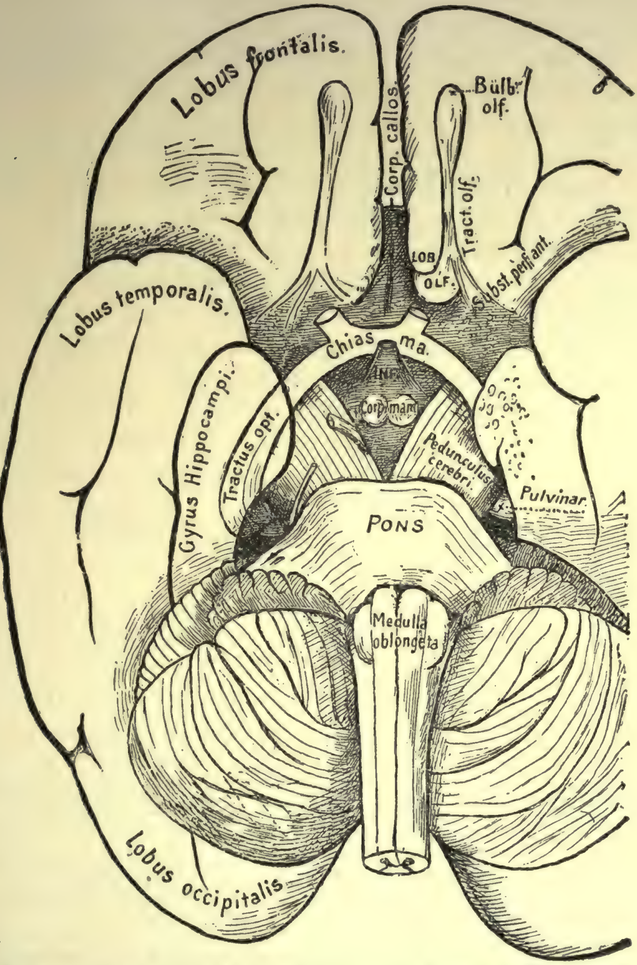

Lobus frontalis.
Corp. callos.
Bulb. olf.
Tract. olf.
LOB
OLF.
Subst. perf. ant.
Lobus temporalis.
Chiasma.
INF.
Corp. mam.
Gyrus Hippocampi.
Tractus opt.
Pedunculus cerebri.
Pulvinar.
PONS
Medulla oblongata
Lobus occipitalis.

Fig. 245.—The Base of the Brain. The Left Lobus Temporalis is in Part Represented as Transparent in Order that the Entire Course of the Optic Tract Might be Seen. (EDINGER.)

Upon the median line it has a groove which follows that of the calamus scriptorius. Upon each side there exist two slight depressions: the one known as the *superior fovea,* the other the *locus cœruleus.*

3. A *superior* face.

4. The *inferior* face is continuous with the base of the medulla oblongata. The annular fibers of the pons embrace as a half-circle the anterior pyramids of the medulla oblongata.

The two lateral faces (5 and 6) are mingled with the origin of the middle cerebellar peduncles. The peduncles sink into the hemispheres of the cerebellum, where they are lost.

Structure of the Pons.—The pons is composed of nerve-fibers and scattered nerve-cells. It forms a kind of knot into which converge the fibers coming from the cerebellum, as well as those passing to and fro from the medulla into the cerebral peduncles.

The *transverse* fibers which form the cortex of this organ go in great part to the middle cerebellar peduncles. They are the commissural fibers which unite one cerebellar hemisphere to the other.

Some fibers emanate from the middle cerebral peduncles and decussate on the median line with those of the opposite side. They thus form the median raphé. They terminate in the gray masses of the pons.

Other fibers, having decussated, bend upward and ascend into the cerebral peduncles. All of the various fibers—semi-annular, horizontal, and oblique—cover in the longitudinal fibers which unite the medulla oblongata to the cerebral peduncles. In them various planes are formed: (1) there is a superficial plane, or *stratum zonale,* which covers the two pyramidal columns; (2) the *stratum profundum,* which separates the pyramids from the fillet and upper part of the pons; (3) the third plane, *stratum complexium,* separates the cerebral tracts. It is this separation which gives rise to the formatio reticularis of the pons and is continuous with the formatio reticularis of the medulla.

Between the superior, or pontal, olives there is a system of fibers which envelops and covers the olivary nuclei to decussate upon the median line back of the pyramids. It is to this system of fibers which unite the nuclei of the auditory nerves and the olives that Edinger has given the name of *trapezoid body.*

The *longitudinal fibers* are in three groups: 1. The anterior bundle, which contains the middle fibers of the cerebral peduncle, and is continuous with the superficial motor fibers of the anterior pyramids of the medulla; farther down it is still in connection with the pyramidal tract of the opposite side of the spinal cord.

2. The *middle column*, or fillet.

3. The third group, the *posterior longitudinal column*, passes along the floor of the fourth ventricle, from which it is separated by a plane of transverse fibers. It is continuous with the anterior column of the cord in order to form the longitudinal commissural column. Some of the fibers of this bundle decussate with their fellows of the opposite side to unite among themselves the nuclei of the motor nerves of the eye and the gray mass of the aqueduct of Sylvius.

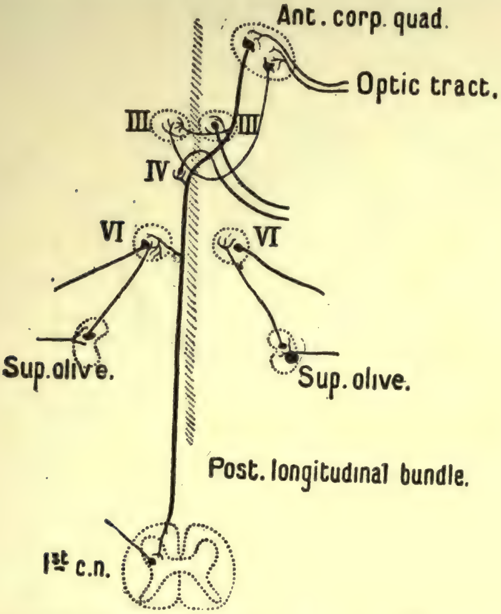


Fig. 246.—Diagram to Illustrate Some of the Connections of the Nuclei of the Nerves to the Ocular Muscles. (Starling, after Held.)

Each bundle is separated from its fellow by a plane of transverse fibers: the strata zonale and profundum.

The *gray substance* of the pons is found isolated in small islands (nuclei of the pons), which are located between the various white layers which have just been mentioned.

One of these nuclei, the most voluminous of all, is situated near the median raphé at the site of the junction of the inferior and middle thirds of the pons. It bears the name of *reticulated nucleus* of the pons. At a slightly higher level is found another, known as the *central nucleus.* To these two nuclei are joined, in part, the root-bundles of the antero-lateral column of the cord.

In addition, as a continuation of the anterior horns of the cord, there exists a nucleus which gives origin to the trigeminus. Inward and somewhat to the front is found a gray mass composed of large multipolar cells. These represent the caput of the anterior horn. It forms the nucleus of origin of the motor root of the trigeminus.

Upon each side of the raphé and very close to the surface of the floor of the fourth ventricle are found other gray nuclei, as of the facial and abducent; also a yellow mass of an S-shape which forms the superior olive of the pons. This latter is connected with the auditory apparatus. The gray substance of the medulla is prolonged into the pons to form the origin of the cranial nerves.

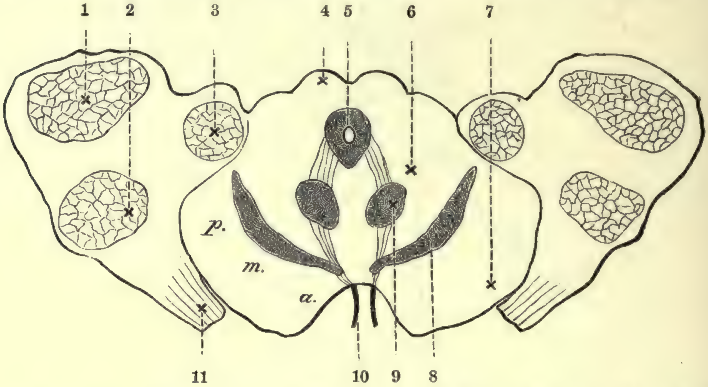


Fig. 247.—Diagrammatic Transverse Section Through the Crus Cerebri and Anterior Corpora Quadrigemina. (Waller, after Obersteiner.)

The letters *a m p* on the pes or crusta signify portions occupied by fibers from the anterior, middle or rolandic, and posterior regions of the cortex.

1, Pulvinar. 2, Corpus genic. lat. 3, Corpus genic. med. 4, Corpora quad. ant. 5, Sylvian aqueduct. 6, Tegmentum. 7, Crusta. 8, Substantia nigra. 9, Red nucleus. 10, Third nerve. 11, Optic tract (divided).

Cerebral Peduncles.

The peduncles of the brain are two white cords which extend from the superior face of the pons in a divergent manner up into the optic thalami. They are somewhat flattened from top to base. Their volume is in direct relation to that of the brain. The peduncles are much larger than the columns of the cord reunited; they contain fibers coming from the gray matter of the medulla, pons, corpora quadrigemina, locus niger, and masses of gray matter lying in a line along the aqueduct of Sylvius. In length the peduncles measure about three-fourths of an inch.

Immediately after their emergence from the pons they separate, each one making its way toward its corresponding hemisphere of the cerebrum. Between them there remains a triangular space, the *interpeduncular space,* filled in its back part by a cribriform white layer containing a great number of vascular openings. The latter is known as the *posterior perforated space.* This space, bounded in front by the optic chiasm, is occupied by the mammillary eminences and tuber cinereum.

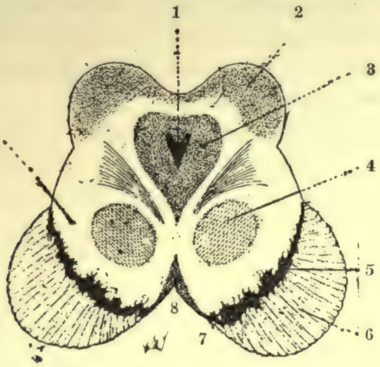


Fig. 248.—Section of the Crus Cerebri. (MORAT.)

The crusta is separated from the tegmentum by the locus niger.

1, Aqueduct. 2, Corpora quad. 3, Vent gray matter. 4, Red nucleus. 5, Locus niger. 6, Crusta. 7, Furrow for the oculo-motor nerve. 8, Sub. perforat. posterior.

Texture of the Peduncles.—A transverse section of the cerebral peduncles gives an idea of the architecture of the large nerve-trunks. In a cut of this kind it is seen that the peduncles are separated into *two white, superposed layers* by a black line: the locus niger.

The inferior level, or *crusta,* of the peduncle is formed in great part by a large, flat, white bundle which is a prolongation of the motor fibers extending to the spinal cord. The crusta extends from the internal capsule through the pons to the ventral portion of the medulla oblongata. From the internal capsule its fibers become lost in the cortical layer of the hemisphere of its own side.

The *crusta* is composed of two bundles, the *internal,* or *cortico-*

pontal, and the *external,* or *voluntary motor, bundle.* The corticopontal bundle acts as a commissure between the cerebrum and cerebellum. It passes from the anterior region of the cerebrum through the peduncles to the pons and medulla, to end in the cerebellum. The voluntary motor bundle descends from the motor regions of the cortex to end in the nuclei of origin of the cranial and the spinal nerves.

TEGMENTUM.—The superior layer of the cerebral peduncle, known as the tegmentum, is chiefly the formatio reticularis and fillet, which consists of masses of gray matter and fibers which extend through the posterior end of the medulla oblongata, pons, and crura up to the optic thalami. At the height of the corpora quadrigemina is a reddish column formed of multipolar cells. It is the red nucleus of the tegmentum.

THE LOCUS NIGER, which separates the pes, or crusta, from the tegmentum, consists of highly pigmented cells. They are like the cells of the motor regions of the cortex. Thus, the locus niger might be considered as a sort of motor ganglion whose cells are charged with black pigment.

The Fourth Ventricle.

The fourth ventricle is a rhomboid cavity (sinus rhomboidalis) imbedded upon the posterior surface of the medulla oblongata and pons. It is the space into which the central canal of the cord opens out superiorly. It is flattened from top to base; and has an inferior wall, or floor; a superior wall, or vault; and four angles.

Floor of the Ventricle.—The floor of the fourth ventricle is lozenge-shaped, being formed by two triangles placed in contiguity at their bases. It is lined by a layer of gray matter, which is but a continuation of that of the cord.

The inferior triangle (calamus scriptorius) belongs to the posterior face of the medulla; the superior triangle to the posterior face of the pons.

Upon the median line of the floor there is a slight groove: the handle of the calamus. On each side of this groove the surface of the floor presents small, rounded, and elongated prominences. These have been described at some length previously, so that now they will be but mentioned. In the inferior triangle, from the handle of the calamus to the restiform body, they are: (1) *trigonum hypoglossi;* (2) *ala cinerea,* or *trigonum vagi;* (3) *trigonum acustici.*

In the superior triangle, upon each side of the median groove and near the base of the triangle, are seen two rounded eminences: (1) *eminentia teres* and (2) the *locus cœruleus.*

The various eminences correspond to the origin of the cranial nerves. Thus, in the locus cœruleus is located the origin of the small root of the trigeminus; in the teres eminentia the common origin of the facial and abducent; in the trigonum hypoglossi is the origin of the hypoglossal nerve; in the ala cinerea, or trigonum vagi, occurs the origin of the motor roots of the glosso-pharyngeal nerves, pneumogastric, and spinal accessory; in the trigonum acustici are found the fibers of the auditory and the sensory fibers of the mixed nerves, glosso-pharyngeal, vagus, and spinal accessory. The trigonum hypoglossi corresponds to the *funiculus teres;* the ala cinerea to a depression: *posterior fovea.*

At the level of the middle of the floor of the fourth ventricle a variable number of striæ go out from the median groove toward the lateral angles. Here they converge somewhat and form, according to some authors, the posterior root of the auditory nerve. The striations constitute the *barbæ* of the *calamus.*

The gray matter of the spinal cord, when it penetrates into the medulla, exposes itself upon the floor of the fourth ventricle. The horns of the central gray column of the cord are found broken up into many parts by the decussation of the pyramids and fillet. By reason of this, the gray matter in the floor of the ventricle represents four irregular, discontinuous longitudinal columns; two are central, with a superficial one on each side. These columns are produced by the bases and detached heads of the anterior and posterior horns of the central gray column. From the anterior gray matter proceed motor nerves; from the posterior gray matter spring sensory nerves.

The *lateral boundaries* of the *ventricle* are, in the lower half, the clavæ of the funiculi graciles, the cuneati, and the restiform bodies. In its upper half the superior peduncles of the cerebellum form the limits.

Aqueduct of Sylvius.

The aqueduct of Sylvius is a canal a centimeter and a half long. It is hollowed out beneath the corpora quadrigemina. By means of this aqueduct the fourth ventricle communicates with the third. It is derived from the middle cerebral vesicle. Its walls are formed above by the valve of Vieussens, the corpora quadrigemina, and the white, posterior commissure. Its base, or floor, is formed by the tegmentum. Its floor is grooved by the continuation of the median groove of the fourth ventricle. Its walls are composed of gray matter continued from the spinal cord.

Fillets.

The chief fillet consists of the axis-cylinders from Goll's and Burdach's nuclei, which decussate under the floor of the fourth ventricle, then pass up through the tegmentum, and chiefly end in the ventral nucleus of the optic thalamus. From new neuraxons it goes through the posterior part of the internal capsule to the ascending parietal convolutions. It is a continuation of the sensory tract.

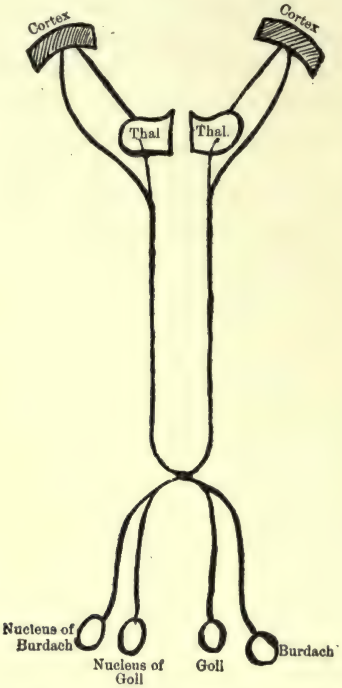


Fig. 249.—The Mesial Fillet, Ending Chiefly in the Ventral Nucleus of the Optic Thalamus and then United by New Neuraxons (Upper Fillet) to Parietal Cortex.

The lateral fillet also starts from the nuclei of Goll and Burdach and is chiefly composed of axis cylinders from the end nuclei of the auditory nuclei and the superior olivary body; it then passes into

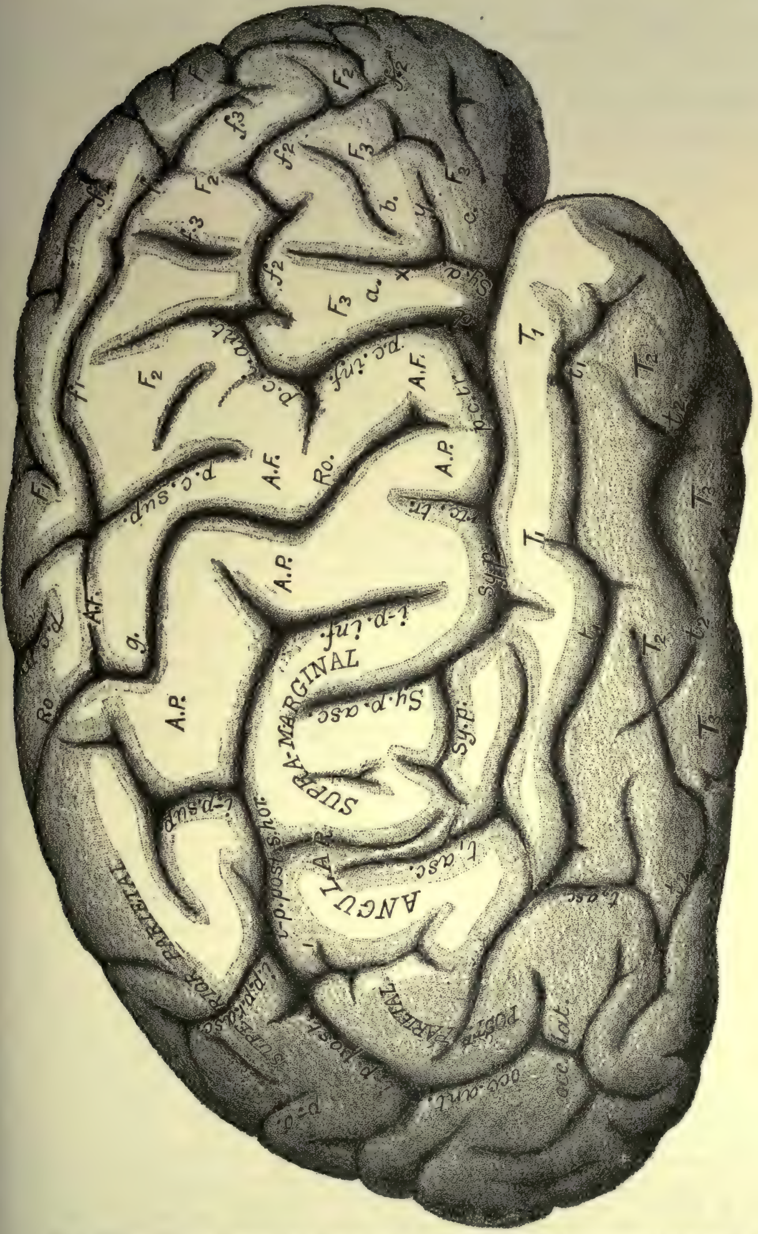

F1
F2
f2
f3
F3
b.
y.
c.
Sy.a.
x
a.
T1
t1
T2
t2
T3
p.c.ant.
p.c.inf.
A.F.
p.c.t.r.
A.P.
Ro.
p.c.sup.
i.c.tr.
Sy.p.
i-p.inf.
SUPRA-MARGINAL
Sy.p.asc.
g.
i-p.sup.
ANGULAR
t.asc.
c-p.post.shor.
PARIETAL
POST. PARIETAL
p.o.s.
occ.sul.
occ.lat.

Fig. 250.—View from the Side and Slightly from Above and Behind of the Right Hemisphere of a Simply Convoluted European Brain. (Quain.)

Sulci—*Ro.*, Rolandic or central. *g*, Its superior genu. *Sy. a*, Anterior limb of Sylvian (*x*, ascending part; *y*, horizontal part). *Sy. p*, Posterior limb of the posterior corpora quadrigemina, and thence by means of the brachium posterioris of the corpora quadrigemina through the posterior limb of the internal capsule to the first and second temporal convolutions. It is made up mainly of auditory fibers.

THE BRAIN.

The weight of the brain is about fifty ounces. However, the weight of the brain may be, as in the case of Cuvier, sixty-five ounces. It is greater in civilized persons than in savage tribes; it is likewise greater in the male than in the female; in an eminent man than in an ordinary man. But what really shows the superiority of the brain is not so much its enormous size nor the exuberance of its convolutions, but the well-balanced development, the harmony, of all of its parts.

External Form.—The brain is composed of two symmetrical halves, or *hemispheres.* These are nearly entirely separated from one another by the *great longitudinal fissure.* The parts which are intact are located at the center and base and comprise the *corpus callosum* and *floor* of the *fourth ventricle.* The surfaces of the hemispheres are separated into lobes and convolutions by various fissures. The convolutions appear to be infoldings of the gray matter of the brain within its rigid confines, the cranial vault. The mode of spreading of the fibers of the peduncle may have something to do with their conformation also. The end obtained by their presence is to lodge a much larger gray mass within a given space.

There are *five principal fissures* in the brain: (1) the *great longitudinal;* (2) the *great transverse fissure* between the cerebrum and

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Sylvian. *Sy. p. asc.*, Ascending ramus of posterior limb. f_1, Superior frontal. f_2, Inferior frontal. f_3, Middle frontal. f_4, Paramesial frontal. *d*, Diagonal, placed in this instance rather low down, and communicating with the Sylvian. *p.c. inf*, Inferior precentral. *p.c.i. ant.*, Its anterior ramus. *p.c. sup.*, Superior precentral. *p.c.m*, Mesial precentral. *p.c. tr.*, Transverse precentral. *rtc. tr.*, Transverse retro-central. *i.-p. inf*, Intra-parietal, pars inferior (inferior postcentral). *i.-p. sup.*, intraparietal, pars superior (superior postcentral). *i.-p. post. s. hor.*, Intraparietal, pars posterior seu horizontalis. *i.p. post.*, Intraparietal, pars posterior (paroccipital of Wilder). *i.-p. pr. asc.*, An ascending branch of the intraparietal. *p.-o.*, Parieto-occipital. *occ. ant.*, Anterior occipital. *occ. lat.*, Lateral occipital. *calc.*, Posterior end of calcarine. t_1, First temporal or parallel. t_1 *asc.*, Its posterior ascending extremity, detached. t_2, Second temporal. t_2 *asc.*, Its posterior ascending extremity joined to and apparently continuous with the first temporal.

Gyri—F_1, F_2, F_3, First, second, and third (superior, middle, and inferior) frontal. *a*, Posterior part of third frontal. *b*, Middle part (pars triangularis). *c*, Orbital part. *AF.*, Ascending frontal. *A.P.*, Ascending parietal. T_1, T_2, T_3, First, second, and third temporal.

cerebellum; (3) the *fissure* of *Sylvius;* (4) *fissure* of *Rolando;* (5) *parieto-occipital fissure.*

As previously stated, the great longitudinal fissure runs antero-posteriorly to separate the two hemispheres of the brain.

At its posterior end and at right angles to it lies the great transverse fissure. By it the posterior portion of the cerebrum is separated from the cerebellum.

The fissure of Sylvius begins at the base of the brain at the anterior perforated space. It passes outward to the external surface of the hemispheres, where it divides into two branches. The one branch passes upward (ascending limb); the other, a larger one, runs nearly horizontally backward (horizontal limb).

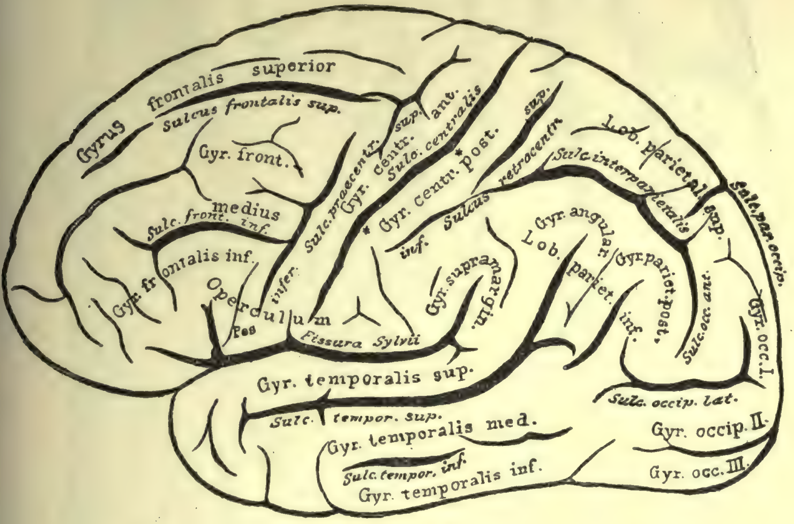
Gyrus frontalis superior
Sulcus frontalis sup.
Gyr. front.
medius
Sulc. front. inf.
Gyr. frontalis inf.
Operculum
Pes
infer.
Sulc. praecentr.
Gyr. centr.
sup.
ant.
Sulc. centralis
Gyr. centr. post.
*
*
sup.
Sulcus retrocentr. inf.
Lob. parietal. sup.
Sulc. interparietalis
Sulc. par. occip.
Gyr. angular.
Lob. pariet. inf.
Gyr. pariet. post.
Gyr. supramargin.
Fissura Sylvii
Sulc. occ. ant.
Gyr. occ. I.
Gyr. temporalis sup.
Sulc. tempor. sup.
Sulc. occip. lat.
Gyr. temporalis med.
Gyr. occip. II.
Sulc. tempor. inf.
Gyr. temporalis inf.
Gyr. occ. III.

Fig. 251.—Lateral Aspect of Brain. (Edinger.)

The gyrus centralis anterior is the ascending frontal convolution. The gyrus centralis posterior is the ascending parietal convolution. Sulcus centralis, fissure of Rolando.

The fissure of Rolando commences at the great longitudinal fissure, half an inch behind its middle point, measuring from the glabella to the external occipital protuberance. It runs downward and forward to terminate a little above the horizontal limb of the fissure of Sylvius.

The parieto-occipital fissure commences about midway between the posterior extremity of the brain and the fissure of Rolando and runs downward and forward for a variable distance.

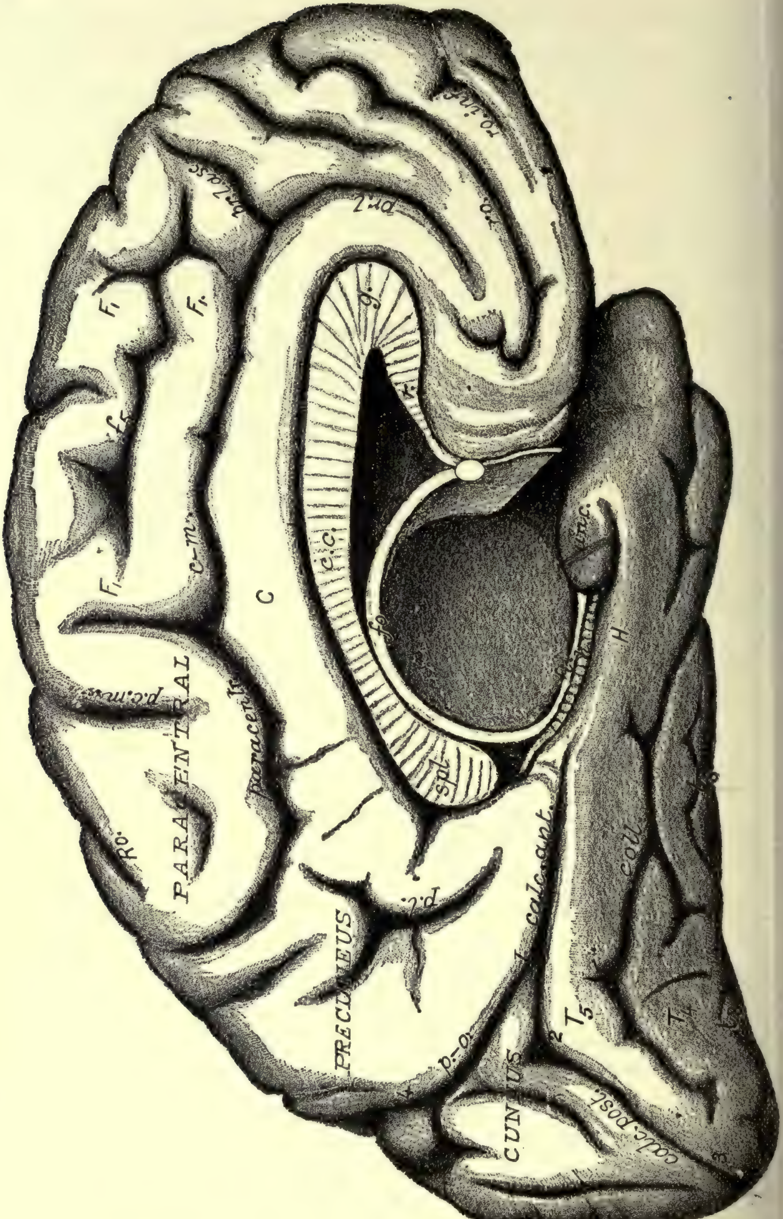
ro.inf.
pr.l.
r.o.
g.
F1
F1
f5
c-m.
F1
C
c.c.
fo
unc.
H
PARACENTRAL
p.c.m.
paracentr.
spl.
Ro.
PRECUNEUS
calc.ant.
coll.
T5
T4
p.-o.
CUNEUS
calc.post.

Fig. 252.—Mesial Aspect of Left Hemisphere of a European Brain. (QUAIN.)

Sulci—*Ro.*, Upper end of Rolandic. *p.c.m.*, Mesial precentral. f_5, Mesial frontal. *c.m.*, Calloso-marginal. *pr. l.*, Prelimbic (anterior end of calloso-mar-

The fissures which have just been mentioned are made use of to map out the surface of the hemispheres into regions to which the term *lobes* has been applied. This mapping is purely artificial and has no clinical or pathological bearing; in many instances the lines dividing the lobes are purely imaginary. However, anatomists are accustomed to speak of six lobes: (1) *frontal;* (2) *parietal;* (3) *occipital;* (4) *temporal;* (5) *limbic,* and (6) *island* of *Reil.*

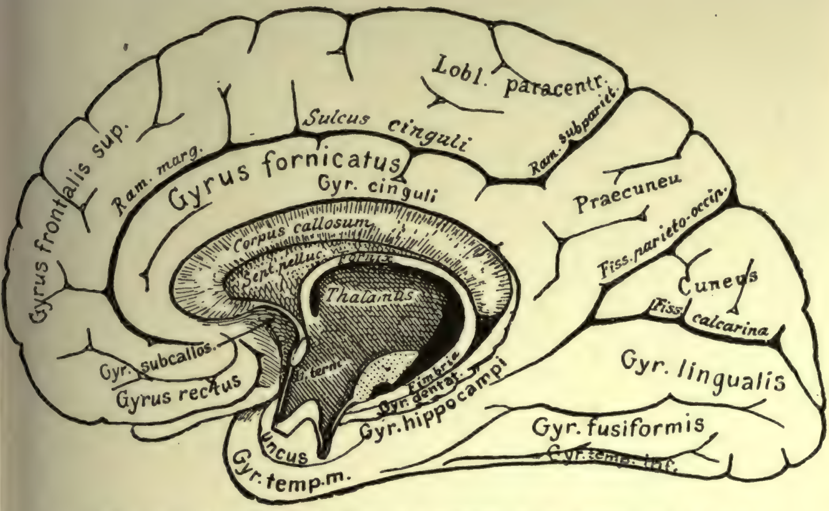
Lobl. paracentr.
Ram. subparietal.
Sulcus cinguli
Gyrus frontalis sup.
Ram. marg.
Gyrus fornicatus
Gyr. cinguli
Corpus callosum
Sept. pelluc.
Fornix
Thalamus
Praecuneu
Fiss. parieto-occip.
Cuneus
Fiss. calcarina
Gyr. lingualis
Gyr. subcallos.
Gyrus rectus
termi
Fimbria
Gyr. dentat.
Gyr. hippocampi
Gyr. fusiformis
Gyr. temp. inf.
Uncus
Gyr. temp. m.

Fig. 253.—Longitudinal Section Through the Middle of an Adult Brain. The posterior portion of the thlamus, the crura cerebri, etc., have been removed, in order to expose the inner surface of the temporal lobe. (Edinger.)

The *island* of *Reil,* or central lobe, is located at the bottom of the fissure of Sylvius. It is a portion of the cerebral cortex which is overhung by the operculum.

The convolution of Broca is that portion of the inferior frontal

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ginal). *pr. l. asc.*, An ascending branch of the prelimbic. *paracentr.*, Paracentral (posterior end of calloso-marginal). *p.l.*, Post-limbic. *ro*, Rostral. *ro. inf.*, Inferior rostral. *p.-o.*, parieto-occipital. *calc. ant.*, Stem of calcarine. *calc. post.*, Posterior part of calcarine. 1, 2, 3, 4, Places where annectent gyri occur in calcarine and parieto-occipital fissures. t_3, Third temporal. *coll.*, collateral or fourth temporal. *h* (placed on the fascia dentata) has the hippocampal fissure just below it.

Gyri—F_1, Marginal part of first frontal. *C*, callosal (gyrus fornicatus). *H*, Hippocampal. *unc.*, Its uncus. *h*, Dentate. T_4, Fourth temporal (fusiform lobule). T_5, Fifth temporal or infracalcarine (lingual lobule).

cc, Corpus Callosum. *spl.*, Its splenium. *g*, Its genu. *r*, Its Rostrum. *fo*, Fornix. *fi.*, Fimbria.

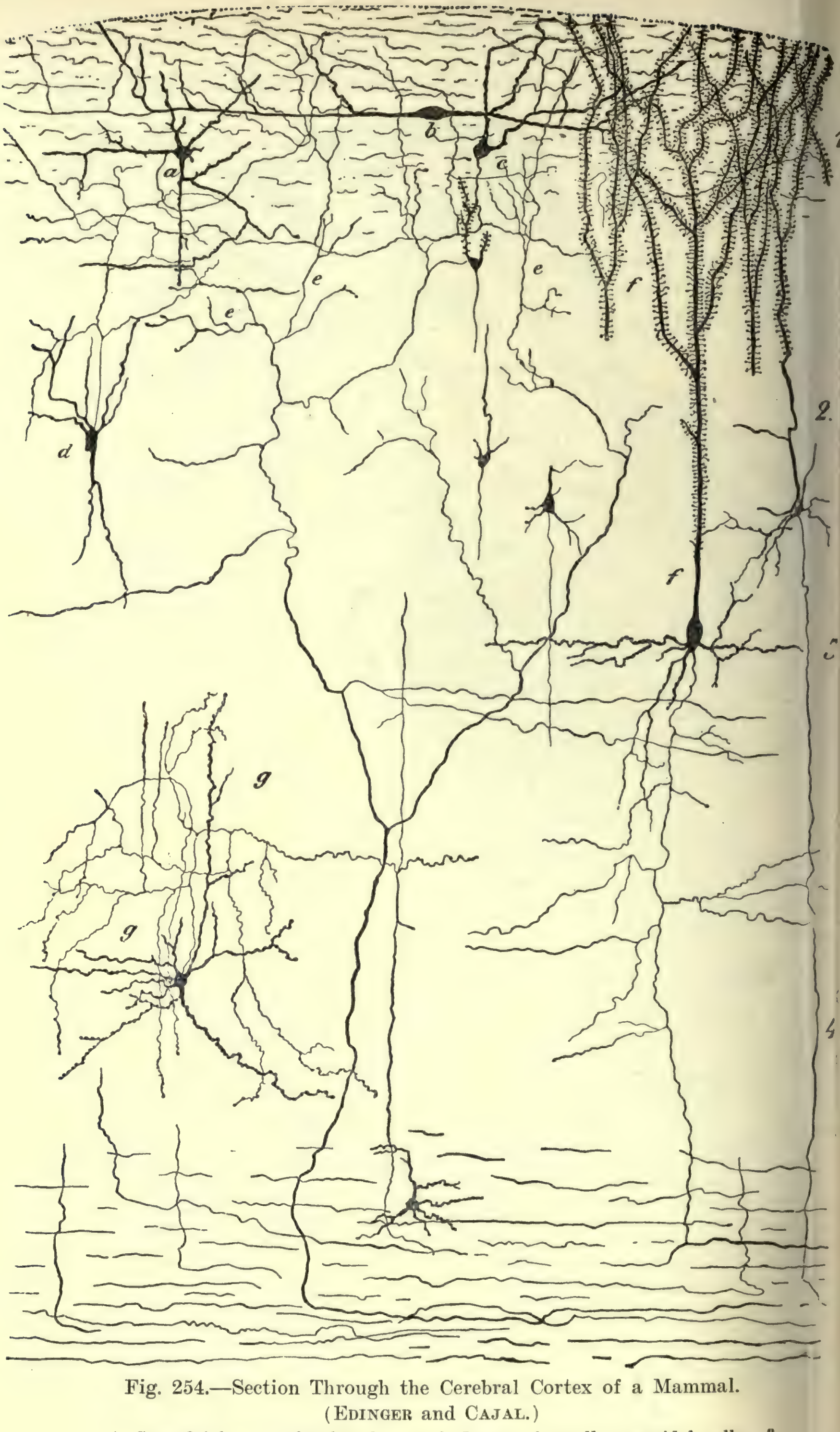

Fig. 254.—Section Through the Cerebral Cortex of a Mammal. (Edinger and Cajal.)

1, Superficial, or molecular, layer. 2, Layer of small pyramidal cells. 3, Layer of large pyramidal cells. 4, Layer of polymorphous cells. *a*, *b*, *c*, Ganglionic cells. *d*, Fusiform cells. *e*, Fibers. *f*, Pyramidal cells. *g*, Multipolar cells.

convolution which winds around the ends of the anterior and ascending limbs of the fissure of Sylvius. It is characteristic in that it is the speech-center and also that it is better developed upon the left side in right-handed people.

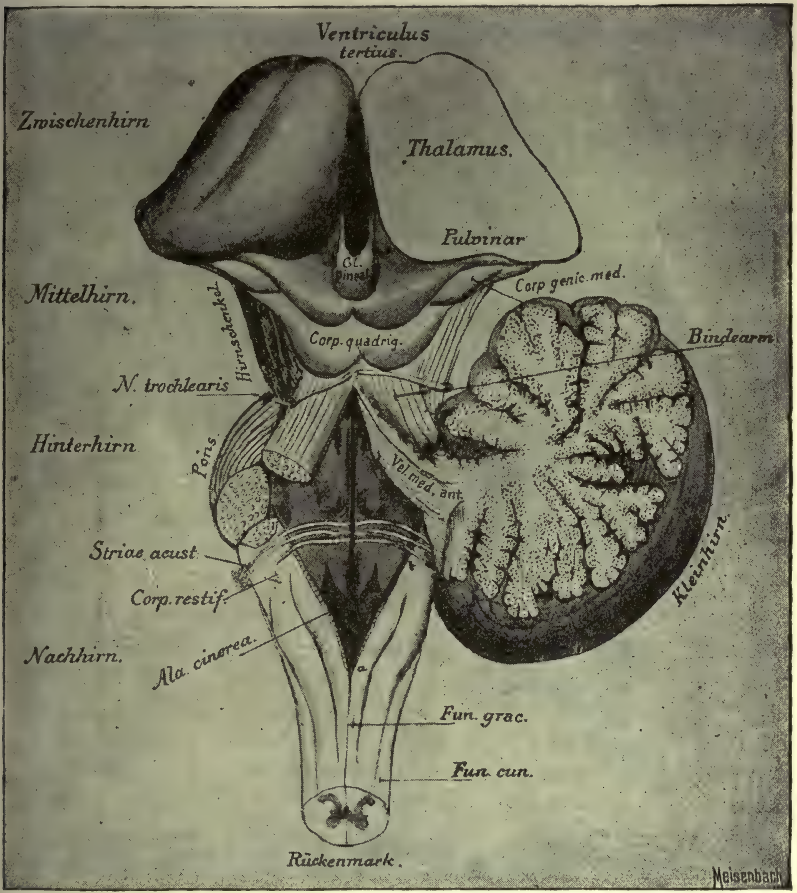
Ventriculus tertius.
Zwischenhirn
Thalamus.
Pulvinar
Gl. pineal.
Corp genic. med.
Mittelhirn.
Hirnschenkel
Bindearm
Corp. quadrig.
N. trochlearis
Hinterhirn
Pons
Vel. med. ant.
Striae acust.
Corp. restif.
Kleinhirn.
Nachhirn.
Ala cinerea.
a
Fun. grac.
Fun. cun.
Rückenmark.
Meisenbach

Fig. 255.—The Brain-structures from the Thalamus to the Spinal Cord (the "Brain-stem"). (Edinger.)

The cerebellum divided, and removed on the left. *Bindearm*, Peduncle. *Hinterhirn*, Hindbrain. *Hirnschenkel*, Crus Cerebri. *Kleinhirn*, Cerebellum. *Mittelhirn*, Midbrain. *Nachhirn*, After-brain. *Rückenmark*, Spinal Cord. *Zwischenhirn*, Interbrain.

On the internal, or mesial, aspect of the hemispheres are the following fissures and convolutions: The convolution immediately bounding the corpus callosum is termed the gyrus fornicatus; the hippocampal gyrus ends inferiorly in a crochetlike extremity, termed the uncus. The gyri fornicatus and hippocampus together form the great limbic lobe; the marginal convolution is merely the internal aspect of the convolutions of the frontal and parietal lobes. That portion which forms the mesial aspect of the ascending frontal convolution is known as the paracentral lobule. Upon the mesial aspect of the postero-parietal lobule is a quadrilateral lobule: the præcuneus.

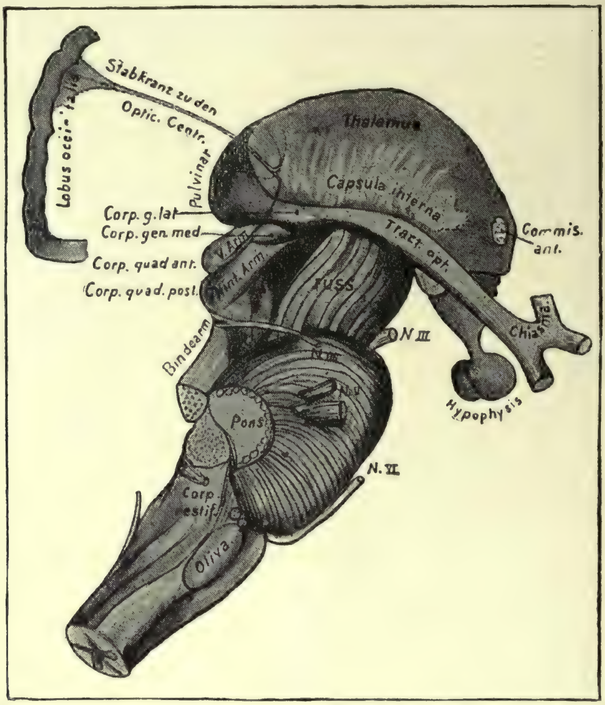
Stabkranz zu den
Optic. Centr.
Lobus occipitalis
Thalamus
Pulvinar
Capsula interna
Corp. g. lat
Corp. gen. med
V. Arm
Corp. quad ant.
Hint. Arm.
Corp. quad. post.
Tract. opt.
Commis. ant.
Fuss
Chiasma
N III
Bindearm
N IV
N V
Hypophysis
Pons
N. VI
Corp. restif.
Oliva

Fig. 256.—Thalamus and Corpora Quadrigemina Seen from the Side. (EDINGER.)

The forebrain removed at the point where its coronal fibers pass into the capsula interna. The relations of the optic radiation to the posterior part of the capsula interna and to the point of origin of the opticus are shown diagrammatically. *Bindearm*, Peduncle. *Fuss*, Pes, or crusta. *Hint. Arm.*, Posterior brachium. *Stabkranz zu den Optic Centr.*, Coronal fibers to the optic centers. *V. Arm.*, Anterior brachium.

Between the parieto-occipital and calcarine fissures is a wedge-shaped lobule called the cuneus.

Structure of the Cerebral Convolutions.—The gray matter of the cerebral cortex has been divided into four layers:—

1. The superficial layer.
2. The layer of small pyramidal cells.
3. The layer of large pyramidal cells.
4. The layer of polymorphous cells.

The first layer contains the cells of Cajal. In this layer terminate many of the fibers coming from the spinal cord, medulla, and cerebellum.

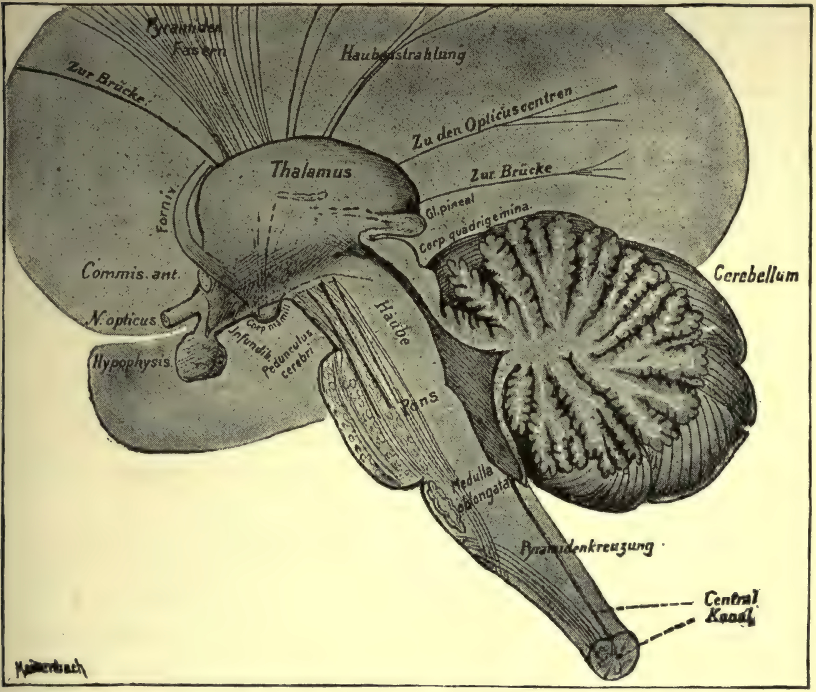
Pyramiden Fasern
Haubenstrahlung
Zur Brücke
Zu den Opticuscentren
Zur Brücke
Thalamus
Fornix
Gl. pineal
Corp. quadrigemina
Cerebellum
Commis. ant.
N. opticus
Hypophysis
Corp. mamill.
Infundib.
Pedunculus cerebri
Haube
Pons
Medulla oblongata
Pyramidenkreuzung
Central Kanal

Fig. 257.—Median Sagittal Section Through the Interbrain and the Structures Posterior to it. (Edinger.)

The course of a number of coronal fibers is indicated by lines: *Zur Brücke*, To the pons. *Pyramiden Fasern*, Pyramidal fibers. *Haubenstrahlung*, Tegmental radiation. *Zu den Opticuscentren*, To the opticus centers. *Haube*, Tegmentum. *Pyramidenkreuzung*, Pyramidal decussation.

The second layer contains the small pyramidal cells, whose axons run into the superficial layer.

The third layer contains the cells of Martinotti, with the large pyramidal cells.

The fourth layer is made up of triangular, small pyramidal, and spindle cells.

The *white matter* of the hemispheres consists of medullated fibers whose size is very various. As a rule, however, they are smaller than those of the cord and bulb. For the most part, they are arranged in bundles separated by layers of neuroglia.

Central Ganglia of the Brain.—At the level of the hilus of the brain the cerebral peduncles sink into the body of the two hemispheres. They contain fibers which proceed from the cord, pons, and cerebellum *to* the brain, as well as those fibers which proceed *from* the brain to the cord, pons, and cerebellum. There are also direct fibers which reach from the peduncles to the brain cortex. However, there are other indirect or ganglionic fibers which communicate previously in the nuclei or ganglia of the gray substance. The ganglia referred to are: the *optic thalami* and the *corpora striata.* The optic thalami are two oval bodies placed upon the tract of the cerebral peduncles. At the posterior part of the thalamus are the external and internal geniculate bodies. Between the pulvinar and the origin of the pineal gland is found a small surface, slightly depressed and of triangular form; it is the triangle of the *habenula.* Within this triangle is a small prominence known as the nucleus of the habenula. The habenula is the peduncle of the pineal gland.

The inferior surface of the thalamus rests upon the cerebral peduncle, from which it receives some fibers. In the rear it remains free, and presents two nipplelike swellings: the *geniculate* bodies. One lies *internal;* the other *external.*

Monakow divides the nuclei of the thalamus as follows: (1) anterior, (2) median, (3) ventral, (4) posterior, and (5) pulvinar. The posterior root-fibers arborize about the nuclei of Goll and Burdach. From there they are continued by a second neuraxon to end in the ventral nucleus of the thalamus.

Each thalamus has a double connection with all parts of the cerebral cortex by neuraxons from its various nuclei to the cortex, and by neuraxons from the pyramidal cells of all parts of the cortex. The neuraxons of the ganglionic cell-layer of the retina end about the cells of the pulvinar and external geniculate body, thus connecting it with the primary division of the optic tract. It has also a double connection with the occipital lobes by neuraxons from the pulvinar cells (optic radiations), which terminate in the pyramidal cells of the occipital cortex and by neuraxons from the pyramidal cells of that lobe which end in the cells of the pulvinar.

Corpora Striata.—The corpora exist as two large ovoid gray masses lodged within the thickness of the frontal lobe. They are situated in front of and slightly outward from the optic thalami. The outer surfaces of the corpora are in relation with the island of Reil and the centrum ovale of the hemispheres. Internally, they are in apposition with the optic thalami and the gray layer of the third ventricle. They are formed of two large nuclei: the *caudate* and *lenticular.*

The *nucleus caudatus* is so named from its resemblance to a pear in shape. It lies inside the lateral ventricle upon its floor. The cells of this nucleus are of two types—sensory and motor; the cells of the motor type seem to be more abundant.

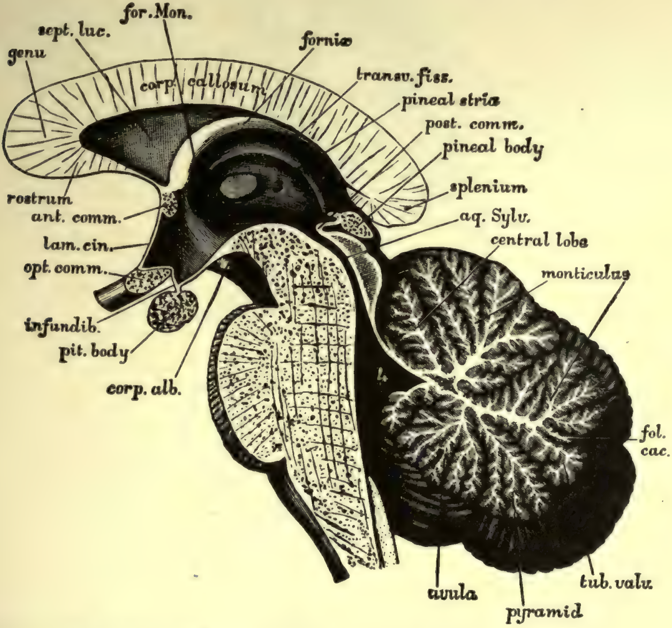
for. Mon.
sept. luc.
genu
fornix
corp. callosum
transv. fiss.
pineal stria
post. comm.
pineal body
splenium
rostrum
ant. comm.
lam. cin.
opt. comm.
aq. Sylv.
central lobe
monticulus
infundib.
pit. body
corp. alb.
4
fol. cac.
tub. valv.
uvula
pyramid

Fig. 258.—Median Section of the Brain. (Quain.)

The *nucleus lenticularis,* a part of the corpus striatum, is separated from the caudate nucleus by the internal capsule. By reason of its situation near the center of the body of the hemisphere and outside of the ventricle it is called the extraventricular nucleus of the corpus striatum.

The lenticular nucleus is *divided* into three segments by two layers of white matter placed within its thickness. The segments are distinguished from one another by their color, which is most pronounced in the external segment. The latter has received the name of *putamen.* The two other segments are known as the internal and external segments of the *globus pallidus.*

Hence it ensues that the corpus striatum has the general character of the letter c. Its upper extremity, or branch, being represented by the caudate nucleus; its lower branch by the lenticular nucleus. The point of union of the two forms the knee. The corpora striata are of cortical origin, and not of central origin, as is the thalamus. That is to say, the nerve-impulses of voluntary movement ordered by the cortex descend to the corpora striata, where they undergo transformation before appearing as muscular movements.

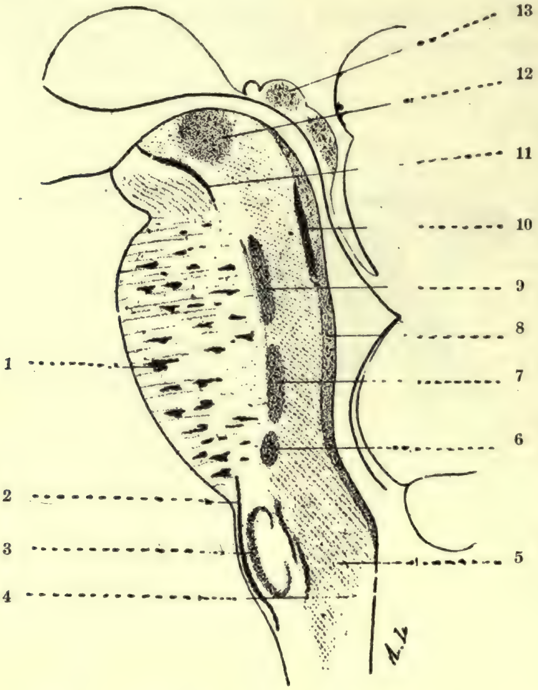

Fig. 259.—So-called Ganglionic Gray Matter of the Cerebral Trunk. (After Charpy.) Gray Masses Superadded to the Sensori-motor Nuclei. (Morat.)

1, Pontal nucleus. 2, Arciform nucleus. 3, Olive. 4, Speech. 5, Reticulat. formation. 6, Trapezoid nucleus. 7, Superior olive. 8, Substant..cin. 9, Lateral nucleus. 10, Locus cœruleus. 11, Locus niger. 12, Red nucleus. 13, Corpora quadrigemina.

The Claustrum.—To the corpora striata is attached a thin layer of gray substance, so placed that it occupies the field between the lenticular nucleus and the island of Reil. This band, derived from the cortex in a manner similar to those fibers of the corpora striata just mentioned, is the *claustrum*. It is separated from the external surface of the lenticular nucleus by a band of white substance: the external capsule.

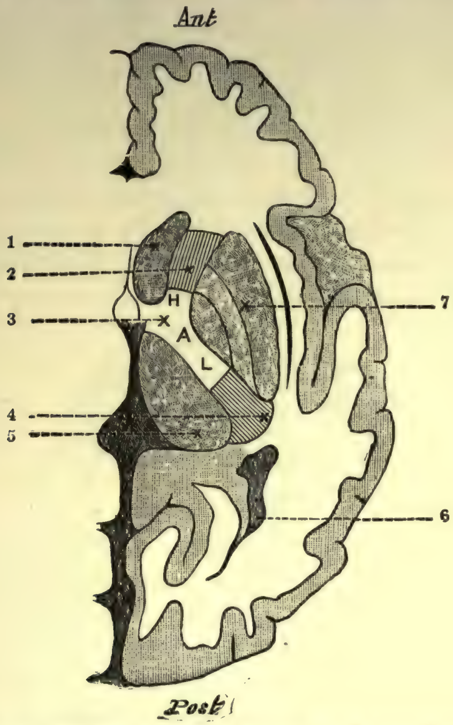

Fig. 260.—Ideal Horizontal Section Through the Right Hemisphere and Basal Ganglia. (WALLER, after CHARCOT.)

To illustrate the position of the internal capsule taken in transverse section; *H A L* indicate the situations in the internal capsule of fibers governing the movements of the head, arm, and leg respectively.

1, Caudate nucleus. 2, Frontal. 3, Genu. 4, Temporo-occipital. 5, Optic thalamus. 6, Hippocampus. 7, Lenticular nucleus.

The claustrum is *composed* of spindle cells, quite like those found in the deep layer of the cortex. The claustrum should be considered as a part of the cortex that has been detached by reason of the passage of a bundle of fibers of association. These fibers unite the various convolutions among themselves.

The *corpora quadrigemina* are four small bodies or rounded eminences. They are composed, for the great part, of gray matter, although covered externally by and containing in their interior some white fibers. They lie beneath the pulvinar of the optic thalamus.

The corpora are arranged in two pairs: one *anterior,* the other *posterior.*

The *upper,* or *anterior, pair* is broader, longer, and darker than the posterior pair. Laterally the corpora extend into distinct and prominent tracts of white substance.

The *lower,* or *posterior, corpora* are composed almost entirely of gray matter.

Internal Capsule.—The name of internal capsule is given to a thick band of white fibers situated between the optic thalamus and caudate nucleus on one side and the lenticular nucleus on the other. In a frontal section of the brain the tract is seen to follow a course upward and outward in an oblique manner between the preceding nuclei. Downward it is continuous with the cerebral peduncle.

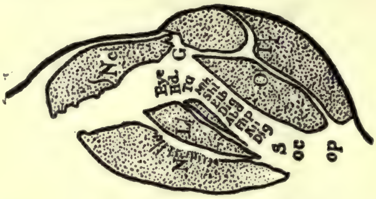

Fig. 261.—Internal Capsule. (SHERRINGTON.)

Where the capsule enters the lenticulo-striate defile it expands like a bundle of stalks to form the corona radiata of Reil.

If studied horizontally, the internal capsule is seen to present the shape of an angle opening outward and embracing the lenticular nucleus. The capsule seems to be composed of two parts or *segments* and a *bend,* or *genu.*

The anterior segment is placed between the lenticular and caudate nuclei; it bears the name of arm, or *lenticulo-striate segment.* The posterior segment, situated between the optic thalamus and lenticular nucleus, for this reason takes the name of *lenticulo-optic segment.*

The point of union of the two segments is called the *knee,* or *genu.* Its position is exactly at the center of the three nuclei just mentioned.

Capsular Structure.—With the naked eye or even a microscope the internal capsule presents itself as a homogeneous structure,

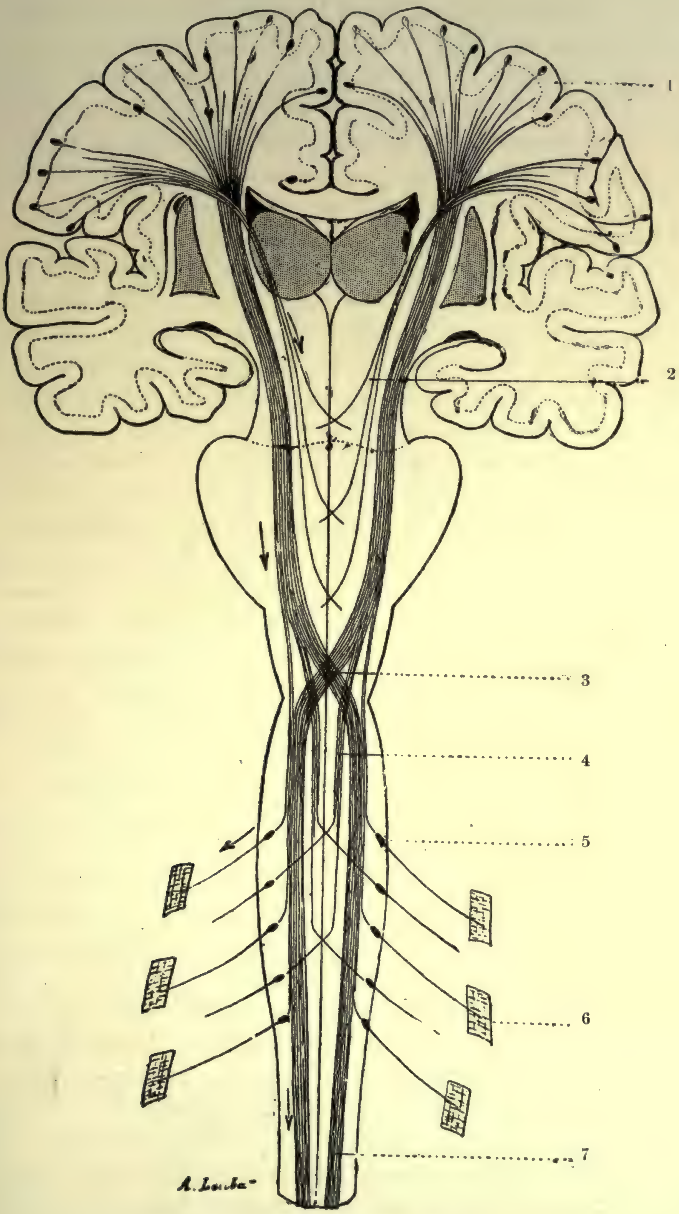

Fig. 262.—Motor Tract. (MORAT.)

1, Pyramidal cell. 2, Geniculate tract. 3, Motor decussation. 4, Türck tract. 5, Cells of anterior horn. 6, Muscle fiber. 7, Crossed pyramidal tract.

composed of white fibers. There is nothing in its appearance to let anyone suppose that there are different tracts or bundles. However, pathological anatomy, with its secondary degeneration, and embryology, by reason of the myelin appearing in the bundles at different stages of development of the fœtus, reveal a number of segments perfectly separated either from a functional or pathological point of view.

The three bundles of fibers are distributed somewhat as follows in the capsule:—

1. *The Cortico-Pontal-Cerebellar Tract* is composed of neuraxons from the pyramidal cells of the frontal lobes. Then the neuraxons pass through the anterior two-thirds of the anterior segment of the internal capsule, then through the crusta, ending in some of the pontal nuclei. These pontal nuclei are joined by neuraxons to the fibers chiefly from half of the cerebellum of the opposite side by the middle cerebellar penduncles, although some fibers are from the cerebellar half of the same side. Hence the frontal lobes are anatomically connected with the opposite cerebellar hemisphere.

2. *The Motor Tract* arises from the neuraxons of the large pyramidal cells of the ascending frontal and paracentral convolutions; then goes through the anterior two-thirds of the posterior segment of the internal capsule; then through the crusta to the anterior pyramids of the medulla oblongata, where they partly decussate, becoming the crossed pyramidal tract of the opposite side of the spinal cord, and ending in the cells of the anterior horns. Part of the motor tract passes down on the side upon which it originated as the tract of Türck, then through the anterior white commissure into the cells of the anterior horn of the opposite side of the cord. Here we have a long neuraxon or axon from the motor convolution to the anterior horns of the opposite side of the spinal cord. From here a second axon starts out to supply the muscles, making only two axons in the motor tract.

The motor tract includes a band of fibers running from the cortex to the nucleus of the various motor cranial nerves. Thus the cortex sends motor fibers to the nucleus of the third, the fourth, the motor division of the fifth, the sixth, the seventh, the motor divisions of the ninth and tenth, and the eleventh and twelfth pairs. We only know the cortical origin of the seventh, the motor branch of the fifth, and the hypoglossal, and these originate from the lowest third of the ascending frontal convolution; then they pass through the knee, or genu, of the internal capsule and continue through the crusta until they end in the nuclei of the various cranial motor nerves.

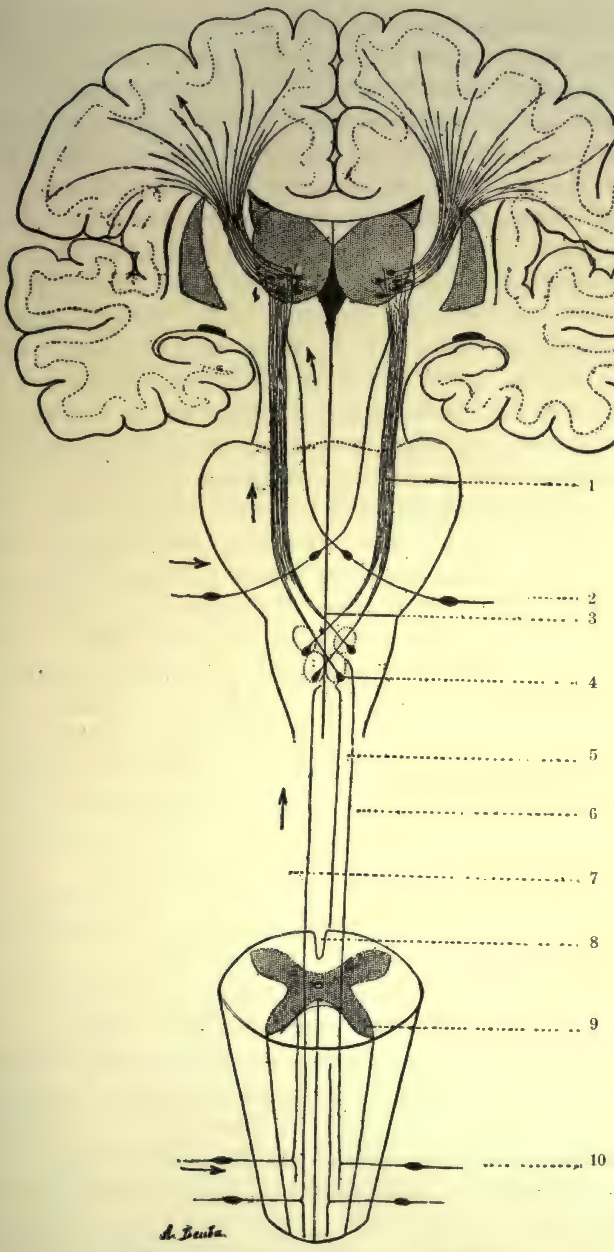

Fig. 263.—Sensory Tract. (Morat.)

1, Fillet. 2, Cranial sensory nerve. 3, Sensory decussation. 4, Nucleus of Goll and of Burdach. 5, Column of Goll. 6, Anterior column. 7, Lateral column. 8, Anterior commissure. 9, Posterior cornu. 10, Spinal nerve.

As this tract passes through the genu of the capsule it is known as the geniculate tract: a part of the main motor tract.

3. *The Sensory Tract.*—Its axons arise in the ganglion of the posterior root and extend from the skin and muscles to the spinal cord, where they divide into an ascending and descending branch. The descending branches arborize about the cells in the gray matter of the cord. The ascending branches in great part ascend in the columns of Goll and Burdach and arborize in the cells of the nuclei of Goll and Burdach. From the nuclei of Goll and Burdach a second series of axons pass under the name of the fillet or lemniscus or interolivary tract, decussating under the floor of the fourth ventricle and chiefly arborize about the cells of the ventral nucleus of the thalamus. From the ventral nucleus a third set of neuraxons arise and go through the posterior part of the posterior segment of the internal capsule to the ascending parietal convolution. This tract receives also the neuraxons of the sensory nuclei of the cranial nerves running to the cortex, excepting the auditory nucleus. In the internal capsule the motor fibers going to the face are in front; next the arm- and then the leg-fibers. Hence lesions occurring in the anterior two-thirds of the posterior limb of the capsule cause motor troubles; lesions in the posterior third cause sensory troubles. The sensory tract is composed of three neuraxons: one from the skin to Goll's and Burdach's nuclei, the second from these nuclei to the ventral nucleus of the thalamus, and the third from this ventral nucleus to the cortex. Pain and temperature sensations travel through the gray matter. Some sensory impulses can travel by way of the cerebellum to the cerebrum.

Blood-supply of the Brain.—The brain is freely supplied with arteries. The brain with its enveloping membrane is said to receive fully one-fifth of the entire quantity of blood within the body.

The brain with its adnexa is supplied by the *two vertebrals* and the *two internal carotids,* with their numerous branches. These principal vessels form a free anastomosis at the base of the brain, known as the *circle of Willis.* The circle is composed of the tip of the basilar, the two posterior cerebrals, the two posterior communicating, the tips of the two internal carotids, the two anterior cerebrals, and the anterior communicating, which connects the two anterior cerebrals.

The nucleus caudatus and the nucleus lenticularis are almost exclusively supplied by the middle cerebral artery, whose branches pass through the foramina of the anterior perforated space. The branches are subdivided into the *lenticular, lenticulo-striate,* and *lenticulo-thalamic arteries.* These vessels pass to their terminations without anastomosing with one another. One of the lenticulo-striate arteries which passes through the outer part of the putamen is very frequently the seat of hæmorrhage. By Charcot it has been named the artery of cerebral hæmorrhage.

The *lymph* finds its way out of the various areas of the brain by means of perivascular spaces in the tunica adventitia of the blood-vessels. These spaces communicate with the subarachnoid space at the surface of the brain.

PHYSIOLOGY OF THE NERVOUS SYSTEM.

Comparison of Nerve and Muscle.—In the study of the general physiology of muscle there was first analyzed its most apparent phenomenon: muscular contraction. Then the forces which provoke muscular contraction were considered, with modifications of muscular excitability.

Practically the same course will be adopted in treating of the general physiology of the nerves. First there will be considered that property comparable to the muscular contraction; in turn will follow a study of the forces which produce the nerve-wave, with modifications also of the nervous excitability.

Thus, there will be established a sort of parallel between nervous and muscular functions; muscular contraction and nerve-wave; muscular irritability and nervous irritability; muscular excitability and nervous excitability.

When a nerve is separated from its nervous centers and no force intervenes to modify its state, then it will remain inert. There will be neither movement nor sensibility. Neither will the nerve come into action unless it be stimulated or excited.

Nerve Excitability.—When a stimulus is applied to a nerve it enters into activity. There are various ways in which this activity is manifested, as by modification of motion or sensation, and besides these external manifestations a latent property in the nerve itself, known as negative variation, which it undergoes during activity. The most striking exhibit of nerve activity is the contraction of the muscle supplied by the nerve. If we would estimate the irritability of a nerve it is necessary to know accurately both the intensity of the stimulus and the result produced. Irritability requires for its due manifestation the integrity of the nerve and an unimpaired circulation and nutrition. But even in a normal state the irritability of the nerve is extremely variable and is in a constant state of instability. Intervals of repose alternating with activity are the most favorable conditions for the maintenance of irritability. When a nerve remains at rest for a long time the irritability diminishes and may even be abrogated, conducing to degeneration of the nerve. Excessive stimulation has a similar effect to destroy the nerve.

For a proper appreciation of so delicate a structure as the nervous tissue and the changes of a fundamental order occurring within it, the student should picture to himself the physical condition of the nerve; how it is composed of molecules in a *state of stable equilibrium.* With this conception he will readily see how any external stimulus may produce molecular movement in one direction and hold them in said position for any variable time.

With cessation of the exciting cause the molecules will be released from their rigid condition and immediately return to their previous normal state. This "return" is the occasion of changes in the opposite direction. Thus, any power that is capable of producing movement in any one direction is sure to be succeeded by movement in the opposite direction as the molecules of the nerve resume their normal, stable equilibrium.

This fundamental principle must constantly be kept before the student's mind, since many of the physiological phenomena of the nervous system are dependent upon it, or their conception is materially aided by remembering it.

IRRITABILITY OF DIFFERENT POINTS OF THE SAME NERVE.—The farther from the muscle the nerve is stimulated, the higher will be the original irritability. It was upon this fact that Pflüger predicated his erroneous avalanche hypothesis: that a nerve-wave gathers force as it passes along the nerve-fiber. The true theory about the fact is that the irritability of the nerve is elevated in the neighborhood of the cross-section by the passage of the demarcation current through that portion. It has been shown by mechanical stimuli that the uninjured nerve has an equal irritability throughout its whole length.

Effect of Heat on Nerves.—Any sudden change of temperature acts as an excitant of a nerve. A temperature below 24.8° F. or above 95° F. applied to a motor nerve of a frog calls out a contraction of the muscle.

If, however, a nerve be gradually frozen it will regain its excitability upon thawing. When a nerve is cooled, in the case of the frog the irritability persists for a long time. If a nerve of a frog is heated to 113° F. its excitability is increased and then diminished.

In the case of a man who plunged his elbow into a freezing mixture, so as to greatly cool the ulnar nerve, there was no contraction, but pain in the parts innervated by the nerve.

CAN A NERVE-FIBER BE FATIGUED?—It has been shown by Bowditch that if you curarize an animal and irritate the nerve for hours, when the curare paralysis of the motor nerve ends and has been removed a muscular contraction of undiminished force ensues.

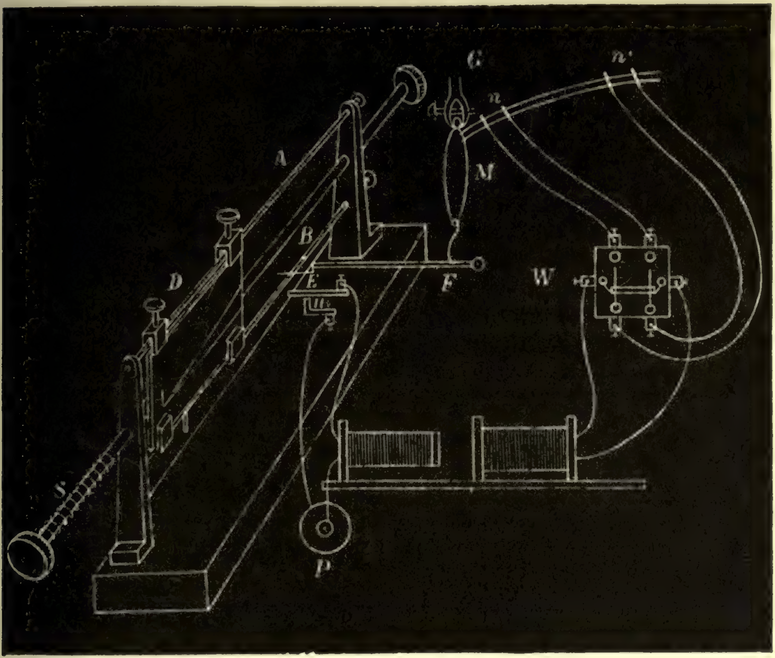

Fig. 264.—*D*, Dubois-Reymond's Spring Myograph to Measure the Rapidity of the Nerve Current in Motor Nerves. (LAHOUSSE.)

***P*, Cell. *W*, Pohl's commutator. *M*, Muscle. *n*, Nerve irritated by an induction nearest to muscle. *F*, Writing pen attached to muscle. *n'*, Nerve irritated by an induction current farthest from muscle. *B*, Smoked plate on which are recorded the movements of the writing pen *F*.**

Inability to fatigue a nerve-fiber occurs in both medullated and unmedullated nerves.

The Transmission of the Nerve-wave.—This demands that the nerve-fiber stimulated be entirely sound. It has the following phenomena: The nerve-wave passes in both directions in both sensory and motor nerves. When a nerve is irritated by an electrical current the electromotive phenomenon of negative variation is seen in both ends of the nerve. Bert's experiment of fixing the end of a rat's tail in a wound in the back and dividing the tail at its root after union has ensued shows that the stimulus is transmitted both ways in the case of sensory nerves. When the root of the divided tail was irritated there followed symptoms of pain, showing that the nerve impulse of sensation was transmitted in a direction opposite to the normal one.

This fact is somewhat difficult of explanation, but in support of it comes Kühne's classical experiment. This investigator takes the sartorius muscle of a frog and separates it lengthwise, beginning at its extremity, so that two small tongues are formed. Each tongue receives nervous filaments from the same peripheral branch. If one of these small tongues be mechanically stimulated the exciting state of the motor nervous fiber is found to be communicated to the other small tongue. Since the second small tongue was excited by a motor stimulus to the first one, it follows that the conduction occurred in a centripetal direction along the course of a motor nerve. This direction is different from that of normal conduction. for the nerve which has been thus excited is a centrifugal motor nerve. Therefore, since the motor nerve has played the rôle of a centripetal conductor in this

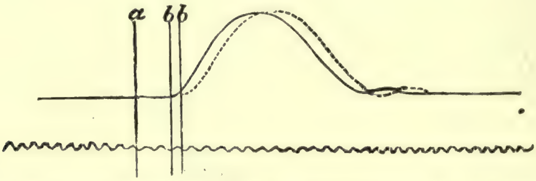

Fig. 265.—Curves Illustrating the Measurement of the Velocity of a Nervous Impulse (Diagrammatic). (Foster.)

To be read from left to right.

The same muscle-nerve preparation is stimulated (1) as far as possible from the muscle and (2) as near as possible to the muscle; both contractions are registered by the pendulum myograph exactly in the same way.

In 1 the stimulus enters the nerve at the time indicated by the line *a*, the contraction, shown by the dotted line, begins at *b′*; the whole latent period therefore is indicated by the distance from *a* to *b′*.

In 2 the stimulus enters the nerve at exactly the same time (*a*); the contraction, shown by the unbroken line, begins at *b*; the latent period therefor is indicated by the distance between *a* and *b*.

The time taken up by the nervous impulse in passing along the length of nerve between 1 and 2 is therefore indicated by the distance between *b* and *b′*, which may be measured by the tuning-fork curve below.

N. B.—No value is given in the figure for the vibrations of the tuning-fork, since the figure is diagrammatic the distance between the two curves, as compared with the length of either, having been purposely exaggerated for the sake of simplicity.

experiment, it follows that a motor nerve can conduct an excitation in both directions.

Swiftness of the Nerve-wave.—Compared with the rapidity of an electrical current, the nerve-current is immeasurably slow. In the motor nerves of a frog Helmholtz made it about 88 feet per second. In the horse Chauveau found it to be about 227 feet per second in the motor nerves of the larynx and only 24 feet in the motor nerves of the œsophagus. In sensory nerves the velocity of the nerve-wave is variable, but may be put down as 150 feet per second. Cold diminishes the swiftness of the nerve-wave. If the intensity of the electrical stimulus is increased the swiftness is increased. The part of a nerve in a state of an electrotonus slows the rapidity of the nerve-current, and this is more perceptible as the duration and intensity of the polarizing current increases. I have found that stretching a nerve lowers the rate of transmission of nerve-force. The method of Helmholtz to measure the velocity of the nerve-wave is as follows:—He stimulated a motor nerve of a muscle and registered the time of its contraction after excitation. After a while the same nerve was stimulated at a point nearer its distribution with the muscle. Its time was also registered. The second time was found to be shorter than the first, so that the difference between it and the preceding must represent the time required between the two excitation points for the transmission of the nerve-wave. The distance between the two stimulated areas being known, one can very readily calculate the swiftness of the nervous action.

Excitability and Conductivity.—Excitability of a nerve is its ability to react to the irritations received by it, not only at one spot, but through its whole length. Conductivity is the property of transmitting through its whole length, up to its terminal extremity, a nerve-wave which has been called out by an irritant. When a part of a trunk of a sciatic nerve of a frog is submitted to the action of carbon dioxide and you stimulate that part, no contraction ensues. But when you stimulate the nerve above this point a tetanus ensues. Here the nerve-wave must travel through the part affected by the carbon dioxide. Hence it is inferred that conductivity and irritability are separate properties in a nerve.

Excitants of the Nerve.—Nerve-excitants are all those forces which modify its state. There are electrical, thermal, mechanical, and chemical excitants. From the fact that they may act upon a nerve in any part of its course, they are frequently designated as *general stimuli.*

The above are the excitants of the sensory and motor nerve. However, it must not be forgotten that in the normal being it is not these forces which come into play to stimulate to activity the motor

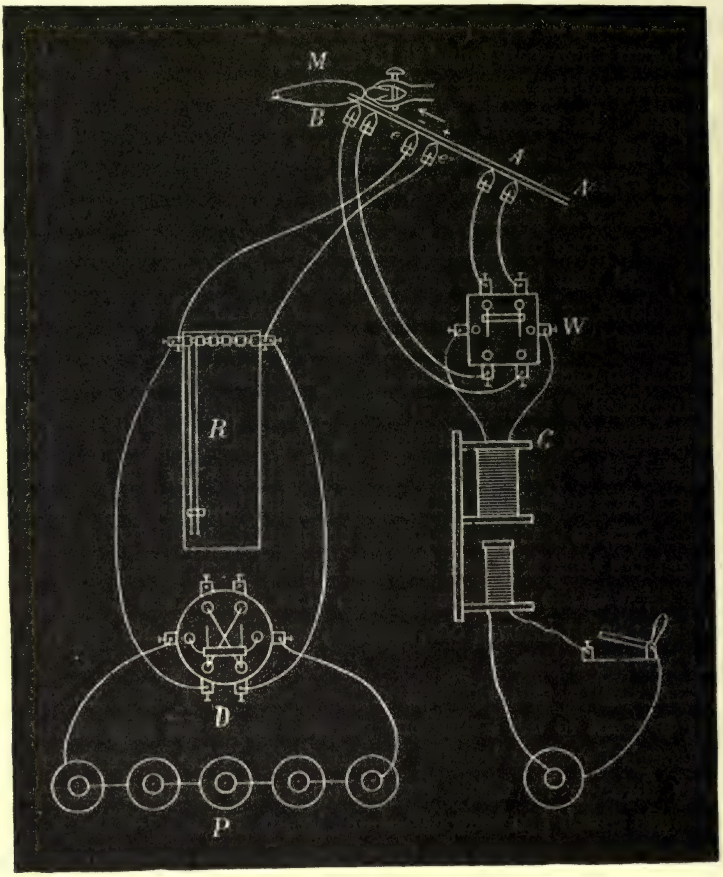

Fig. 266.—Method of Studying Physiological Electrotonus. (Lahousse.)

P, Five Daniell cells. *R*, Rheocord. *D*, Pohl's commutator to make either ascending or descending current. *e*, *e*, Unpolarizable electrodes. *N*, Motor nerves. *M*, Muscle, to be attached to a myographic lever. *C*, Induction current which can be sent to *A* or *B* by the commutator *W* with the cross bars removed.

Supposing we have a descending constant current passing through the nerve, then an induced current will not make the muscle contract when it is applied at *A* in the extra polar anelectrotonic region of the nerve. Before the passage of the constant current the induction current of the same strength as before caused a minimal contraction. On the contrary, an induced current when sent to *B*, that is, in the katelectrotonic region of the nerve, causes a maximal contraction instead of the minimal contraction previous to the passage of the constant current.

nerve. The normal excitant is the physiological stimulus; it is the *will.* It originates within the nerve-centers, from where it is transmitted to the motor nerve. Any stimulus when applied to a nerve causes the molecules in that localized area to vibrate and so produce certain electromotive changes. By the changes set up in this particular area of nerve, the contiguous parts are also necessarily brought into activity by reason of nerve-conduction. By many authors this transmission of changes along the course of the nerve so as to act as excitants is known as the true physiological stimulus. Thus, the vibrations in each segment perform the function of excitant for each succeeding segment.

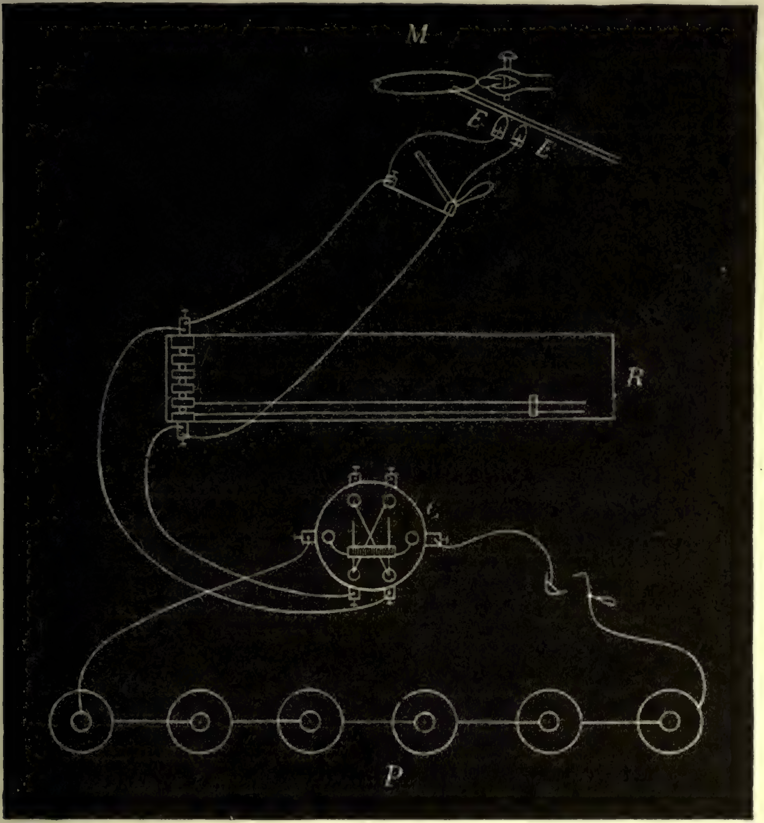

Fig. 267.—Schema of Apparatus for the Study of the Law of Contractions in the Frog. (LAHOUSSE.)

P, Daniell cells. *C*, Pohl's commutator. *E* and *E*, unpolarizable electrodes applied to sciatic nerve. *R*, Rheocord.

ELECTRICAL EXCITANTS.—This form of stimulus is surely the most important to study and is, perhaps, the one that is most complex. The electrical stimulus may consist of either the constant or interrupted current. The stimulation of the nerve may be direct, as when the electrodes are applied to the nerve. There are two kinds of currents used: the induction current and the galvanic current. I shall take up the constant current.

ELECTROTONUS.—When a constant current traverses a nerve it alters its excitability, conductivity, and electromotivity. This is called electrotonus. The part of the nerve affected by the positive pole is said to be in a state of anelectrotonus, the part altered by the negative pole to be in a state of katelectrotonus. Intrapolar means between the electrodes or poles; extrapolar is outside the poles. Descending current is down the nerve to the muscle; ascending current is from the muscle up the nerve. By the action of the constant current on the nerve-muscle preparation at the time of making and breaking of the same we have the contraction law of Pflüger. As an aid to memory we shall call the contraction "yes;" no contraction, "no."

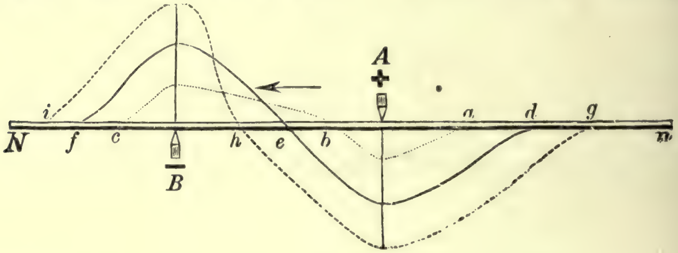

Fig. 268.—Scheme of Electrotonic Excitability.

The nerve (*N-n*) is traversed by a constant current in the direction of the arrow. The curve shows the degree of increased excitability in the neighborhood of the cathode (*B*) as an elevation above the nerve; diminution at the anode (*A*) as a depression. The curve *i-h-g* shows the degree of excitability with a strong current; the curve *f-e-d* with a medium current, and the curve *c-b-a* with a weak current. *A*, is anode. *B*, is cathode.

	Descending current.		Ascending current.	
Strength of current.	Make.	Break.	Make.	Break.
Weak	Yes	No	Yes	No
Moderate	Yes	Yes	Yes	Yes
Strong	Yes	No	No	Yes

EXPLANATION OF PFLÜGER'S CONTRACTION LAWS.—These laws are explained by the fact that a sudden increase of excitability at the kathode at the make of a current, or a sudden change of excitability from below normal to normal, or above, at the break of the current at the anode, acts as stimuli to the muscular contraction. The constant current, independent of the changes in excitability, lowers the conductivity of the nerve. With the exception of the weakest current, the conductivity at the kathode and the anode is diminished, and with currents moderately strong the conductivity is blocked.

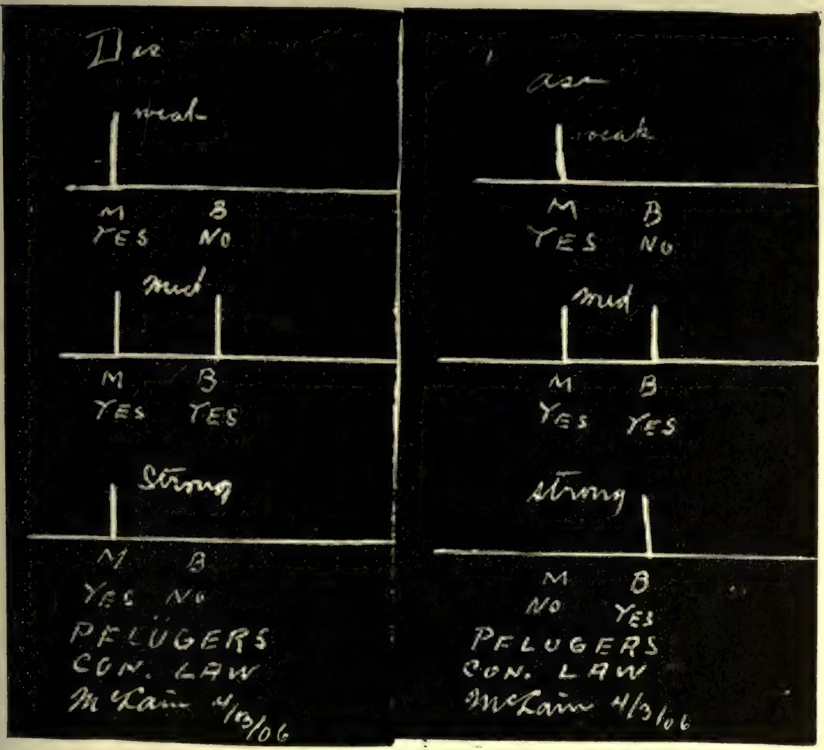
Des
weak
M B
YES NO
mid
M B
YES YES
Strong
M B
YES NO
PFLUGERS
CON. LAW
McLain 4/03/06
asc
weak
M B
YES NO
mid
M B
YES YES
strong
M B
NO YES
PFLUGERS
CON. LAW
McLain 4/3/06

Fig. 269.—Pflüger's Law of Contraction or Nerve-muscle Preparation.

Des, Descending current. *Asc*, Ascending current.

The conductivity at the anode is but little affected and is much higher than at the kathode, so that at the time of full kathodic block the nerve-impulse still freely travels through the region around the positive pole. With stronger currents, conductivity at the anode diminishes so much in the intrapolar region that it blocks the nerve-impulse, but this is to be looked upon as a stretching of the diminution of conductivity which has crept along the intrapolar area from the kathode.

With ascending current: 1. If the current is strong, the intrapolar anelectrotonic part of the nerve loses its conductivity, the stimulus at the kathode at the make is not transmitted to the nerve, and no contraction follows. Loeb explains electrotonus by an increased and diminished concentration of the ions of calcium and magnesium at the kathode and anode. At the breaking of the current the anelectrotonus disappears, stimulation is produced at the anode, and the muscle contracts.

2. If the current is moderate, the conductivity of the anelectrotonic part of the nerve is not much affected and the stimulus produced at the opening and closing of the current is transmitted to the muscle, which contracts.

3. With weak currents, the stimulation is only active at the point farthest from the muscle and the closing produces contraction.

With descending current: 1. With strong currents the stimulus at the kathode at the make produces a contraction, as kathode is nearest the muscle, but the stimulation of break at anode is not conducted on account of the lowered conductivity of the intrapolar anelectrotonic part and the kathodic part is not immediately passable after a strong current.

2. With moderate current, contraction ensues on the opening and closing of the current for the same reasons as in the case of the ascending current.

3. With weak current, the onset of katelectrotonus is a more powerful stimulant than the disappearance of the anelectrotonus; the effect of the latter is too slight to manifest any action.

The same law is applicable in the electrotonus of muscle.

Katelectrotonus diminishes electromotivity, while anelectrotonus increases it.

Contraction Laws in Man (Waller).—A pair of electrodes cannot be applied to a nerve in man so as to send a current in at one and out at another point; so you cannot have ascending and descending currents. One electrode must be applied to a nerve, the second, where convenient, to some other part of the body. If the electrode be the anode of a current, the latter enters the nerve by a series of points and leaves it by a second series of points; the former series of points forms the polar zone or region, the latter or distal series of points the peripolar zone or region. In such case the polar region is the seat of entrance of current into the nerve, that is, the anode; the peripolar region is the seat of exit of current from the nerve, that is, kathode. Practically, a kathode and anode exist about each pole in the tissues.

If, on the contrary, the electrode under observation is the kathode, the current enters the nerve by a series of points which collectively constitute a peripolar region and it leaves the nerve by a series of points which collectively constitute a polar region. The current at its entrance into the body diffuses widely, and at its exit it concentrates; its density is greater close to the electrode, and the greater the distance of any point from the electrodes the less the current density at that point. Hence it is obvious that current density is greater in the polar than in the peripolar region. Waller makes the formula for man as follows:—

Weak current	K. C. C.	....	....	....
Medium current	K. C. C.	A C. C.	A. O. C.	....
Strong current	K. C. C.	A. C. C.	A. O. C.	K. O. C.

K. C. C. = Kathodic closure contraction.
A. C. C. = Anodic closure contraction.
A. O. C. = Anodic opening contraction.
K. O. C. = Kathodic opening contraction.

Making "yes" for contraction and "no" for rest we have:—

	KATHODE.		ANODE.	
	MAKE.	BREAK.	MAKE.	BREAK.
Weak current	Yes	No	No	No
Medium current	Yes	No	Yes	Yes
Strong current	Yes	Yes	Yes	Yes

Reaction of degeneration denotes the reaction of diseased nerve and muscle on man. As regards the nerve, the reaction of degeneration consists in the abolition of excitability to the induced current, while the excitability to the constant current is exaggerated; the muscular contraction is also greatly prolonged and galvano-tonus (tonic contraction) is easily produced. The normal contraction formula just given is departed from, the most characteristic feature of this departure being a reversal of the normal order of appearance of K. C. C. and A. C. C. Normally, K. C. C. appears with a weaker current than A. C. C. In a well-marked reaction of degeneration A. C. C. appears with a weaker current than K. C. C. There is no satisfactory explanation of this reversal (Waller).

The musical symbols < > (crescendo and diminuendo) indicate increase and decrease. They are used in electrical formula to show the relationship of one reaction of muscle becoming greater than another. Thus: A. C. C. > K. C. C. = the anodic closure contraction becoming greater than the kathodic closure contraction. In neuralgias the anode is placed upon the painful nerve.

The Faradic current is a more effective stimulus to nerves than a galvanic current, for the effectiveness of a current as a stimulus depends not only upon the total variations in intensity, but also upon the amount of such variation in the unit of time; that is, the greater the rapidity of the total variation, the more effective is the current as a stimulus.

In the Faradic current the kathode is always more active in producing contractions. The short duration of the opening and closing of the induction currents makes them fused in effects.

Electrotonic Variation of Electromotivity.—Electrotonus not only changes the irritability and conductivity, but also the electromotivity of a nerve. If a nerve is connected with nonpolarizable electrodes in such a way that its transverse section is laid on one and its surface on the other, then the galvanometer will show the presence of a strong nerve-current. If, now, a galvanic current is passed through the extremity of the nerve outside the unpolarizable electrodes, the polarizing current is established. The electrotonic current in the nerve always has the same direction as the polarizing current.

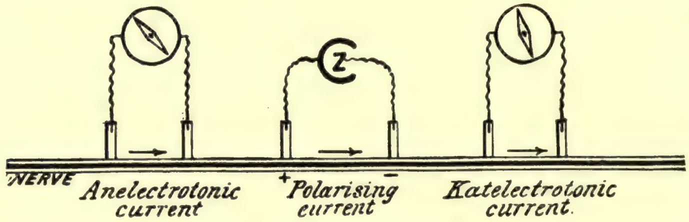

Fig. 270. (Waller.)

In the extrapolar kathodic region an electrotonic current is generated when the polarizing current is closed. In the anodic region the electrotonic current is stronger than the kathodic current.

These electrotonic currents are only found in medullated nerves, and are only produced by an electrical polarizing current. Nonmedullated nerves, muscles, and tendons do not show them. The electrotonic currents are not the action-currents of a nerve, and must not be confounded with them.

The experiment of paradoxical contraction depends upon electrotonic currents.

Reflex Action.—A motor reflex act is the transmission of an irritation by the neuraxon of a sensory neuron to the dendrons of a motor neuron and by its neuraxon in turn to the muscle.

The functions of the gray substance of the nervous centers can be known only through reflex movements; so that, to study reflex action is to study the nervous centers.

From a knowledge of the principles of a reflex action it will be seen that three stages must be considered: 1. The external excitation which goes to excite the nervous centers through the sensitive nerves as a medium. 2. The excitation of the nervous centers which receive the irritation and then transform and modify it; through the medium of the motor nerves it is communicated to the muscles. 3. The contraction of the muscle thus innervated.

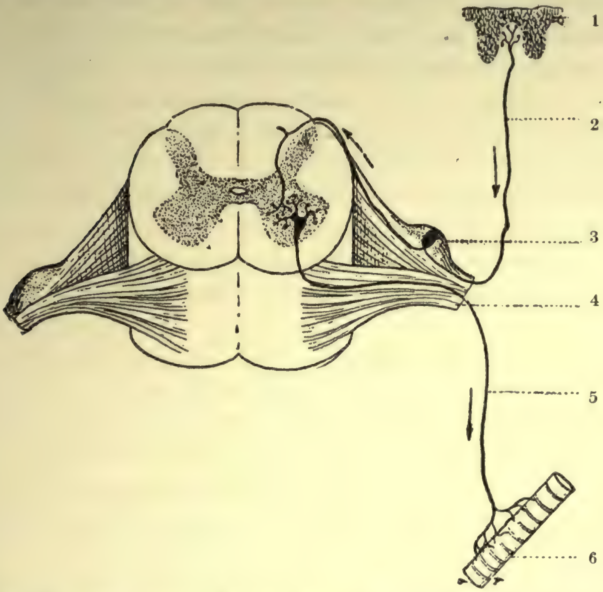

Fig. 271.—Elementary Reflex Arc. Course of Sensory Impressions and a Motor Impulse, Passing Through the same Level of the Spinal Cord. (Morat.)

1, Skin. 2, Sensory nerve. 3, Posterior root ganglion. 4, Anterior root. 5, Motor nerve. 6, Muscle.

Other Seats.—It is not only in the spinal cord properly so called that there are reflex acts. There are some in the *medulla oblongata*, in the *pons*, and in the *gray* parts of the brain.

The physiological study of strychnine shows what intimate connections exist between the different parts of the spinal cord. The irritation of the periphery at any point whatever, being transmitted to the spinal cord by a sensitive nerve, goes to provoke at once the activity of the whole organ.

The initial stimulation for a reflex action may arise from any sensory nerve, whether of special sense, touch, or visceral supply. But there are some which generate a more active reflex movement, among which may be mentioned those of the palm of the hand and the sole of the foot. The quality and nature of the stimulus used has an influence on the reflex. Thus, tickling the auditory meatus produces cough; excessive sunlight acting on the retina causes sneezing. Stimulation of a sensory nerve-trunk in any part of its course calls out a reflex action, but the movement in this case is much less energetic and its character altered. In such a case the stimulation causes movement in one or more muscles, while stimulation of the skin surface innervated by the same nerve produces movements which have a peculiar character of co-ordination. To produce a reflex action the application of the stimulus must be sufficiently rapid.

Any agent which produces a slow and gradual change in the nerve is without effect. Some experimentalists have found a difference between the reflex of chemical and of mechanical stimulation. When the reflex center has a greater or less excitability, then the stimulation produces greater or less results. Every center which gives origin to a motor nerve may be looked upon as a reflex center. The excitability of the reflex centers is increased when their connection with the cerebrum is cut off or when the latter centers are inactive. Hence after decapitation, removal of the brain, section of the oblong medulla, or section of the spinal cord, the centers below the section have greatly increased activity in their reflexes. Setschenow has shown that mainly in the optic thalami and corpora quadrigemina are seated centers inhibiting the activity of the spinal reflex centers.

Reflex excitability is much greater in young animals than in adults. This explains the quickness with which slight causes produce convulsions in the infant. Reflex activity is greater in the summer than in the winter. Certain toxic agents have an effect on the reflexes. Thus, atropine, bromides, chloral, chloroform, and ether reduce reflex activity, while strychnine greatly excites it. Chloroform is poisonous to every living cell, whether of plant or of animal life. Strychnine is only poisonous to the nerve-cell, not to the plant-cell.

Every time that intellectual action is suppressed then are the reflexes more manifest. A person asleep has more energetic reflex actions than a person awake. In somnambulism the action of the will is nearly suppressed, while the reflex excitability of the cord is enormously increased.

On the other hand, a person by exercising a strong will can arrest certain reflexes. Thus, the conjunctival reflex can be prevented by the will of a courageous person. Up to a certain point a person is able to resist sneezing or coughing, which are certainly typical reflex movements.

SWIFTNESS OF REFLEX ACTIONS.—Helmholtz succeeded in measuring by the graphic method the switfness of the spinal actions. By him it was ascertained that the excitation travels in the spinal cord at the rate of *about twenty-four feet per second.*

LAWS OF REFLEX ACTIONS.—They are the law of *localization* and that of *irradiation.* One other accessory law will be added: the law of *co-ordination.*

Law of Localization.—If any sensitive region be excited, the first reflex movement which will be produced will bear upon the muscles near the sensitive region excited.

Thus, if the foot of a frog be very lightly touched, the muscles of that foot will respond reflexly. If the conjunctiva be touched, the reflex movement will be in the orbicular muscles.

Law of Irradiation.—When an excitation has produced a reflex movement in the muscles of one side by a first degree of irradiation, there will be reflex movements in the corresponding muscles of the opposite side. Cutaneous constriction by cold applied to the right hand determines constriction by the vasomotors of the left hand as well. These are examples of the type known as *transverse irradiation.*

If the excitation be more intense, the movement is spread into the muscles situated above and below the point of excitation. This represents the *longitudinal irradiation.*

Law of Co-ordination.—The law of co-ordination or adaptation of the reflex actions in decapitated animals is very striking. If a drop of acetic acid be placed upon the back of a decapitated frog the animal will make such movements with the feet that it seems to want to free itself from the substance which irritates it. They are not blind movements, but such as seem to be adapted to an end and are co-ordinated.

Reflex Tonus of Spinal Cord.—It cannot be denied that, in the normal state, there is always a certain spinal tonus. That is to say, an active state of the cord which is provoked by sensory excitations. All of the muscles of the organism, striated as well as smooth, are always in a state intermediate between relaxation and contraction. This state of semiconstriction, of semiactivity, is governed by the spinal cord. When the spinal cord is destroyed, immediately all of the muscles of the body relax and their tonus ceases.

Influence of the Blood.—If a limb be separated from the rest of the organism, and, consequently, receives no nutritive blood-current, the *function of the nerve nevertheless persists.*

By making Stenson's experiment (tying the abdominal aorta), at the end of twenty minutes, or an hour at the most, it will be found that sensibility and motility disappear in the abdominal members. Though the deprivation of blood be complete, still there is preservation of the nervous activity for some time.

By using on man the ligature and then compressing the limb by an Esmarch bandage interesting observations upon the influence of anæmia are made. During the first twenty minutes the arm is sensitive and the cutaneous excitations are plainly perceived. Likewise the motor nerves can still command the movements of the muscles.

Soon, however, the sensibility becomes obtuse; the voluntary movements take place only incompletely, without force, and slowly. Next the sensibility disappears so completely that the strongest electrical excitations are not felt. Because of the powerlessness of the motor nerves, the limb feels limp and inert as if it were completely paralyzed.

This state of death of the nerves, from anæmia, contrasts with the survival of the muscles. The nerve dies before the muscle, but much later than the nervous centers.

EXCITING EFFECTS OF ANÆMIA.—However it may be, anæmia, which makes the functions of the nerve finally disappear, begins *at first* by overexciting it. Thus, the first effects of anæmia are marked by an increase of excitability. If it be a sensory member, anæmia of it provokes extremely lively pains.

Physicians have long been acquainted with painful anæmiæ. It is anæmia, not absolute, but relative, which is often the cause of intense peripheral pains. Thus, in symmetrical gangrene of the extremities (Raynaud's disease), which is characterized by nearly complete cessation of the circulation in the affected areas, the pain is very acute. There is extreme hyperæsthesia, probably due to nervous anæmia.

Physiology of the Spinal Cord and its Nerves.

The spinal cord represents: 1. A great *conductor* whose extent lies between the brain and periphery of the body. Along it are transmitted centrifugal as well as centripetal actions; the former carry volitional impulses to the muscles, the latter impressions from the sensitive surfaces to the brain. By reason of the spinal cord having in its composition innumerable nervous cells, it becomes a coördinator of the actions which pass over it.

2. The spinal cord represents a *true nervous center.* It may be either an important center of reflex phenomena in that its cells unite centripetal fibers with centrifugal ones, or it may possess the rôle of acting as a special center of the special functions.

Cord as a Conductor.—The law of Bell is enunciated as follows: *"Of the roots which issue from the spinal cord, the anterior are those of motion and the posterior those of sensation."*

This law is very clearly demonstrated by the so-called Müller frog. If the last four *anterior* spinal roots in the cauda equina of a frog are cut off at the *right,* and the last four *posterior* roots are cut off at the *left,* the animal after recovering from the operation will present interesting conditions. The right lower leg will be *paralyzed;* that is, deprived of voluntary motion. The left lower leg will be *anæsthetic:* that is, deprived of sensation, but still possess motion. Therefore, the anterior spinal roots are motor and the posterior ones sensory.

Irritation of the posterior roots, or of their central stumps, determines sensations. These sensations are sharp pains in the regions innervated by the particular nerve. Excitation of the peripheral stump is without any effect.

Irritation of the anterior roots, or of their peripheral stumps, determines movements. These movements are of the nature of convulsive cramps in the particular muscles innervated. Excitation of the central stumps is not followed by any effect.

Cutting off, or the complete destruction, of the posterior roots causes the loss of tactile, thermic, and painful sensibilities; also of muscular sensation in the parts where they are distributed. Section of the anterior roots wholly paralyzes the muscles innervated by them.

Apparent Contradiction.—In demonstrating Bell's law there occasionally are seen results which seem to contradict that law, but instead they really confirm it. It is found that in stimulating the anterior (motor) root with electricity the animal sometimes gives evidences of pain. The same thing may occur also after cutting it in the middle and then stimulating, not the central, but the peripheral stump. Bernard has explained the sensibility of the anterior root by admitting that the *recurrent sensitive fibers,* which, taking their departure from the posterior roots, run back from the periphery towards the center on the anterior root. If the posterior root be cut near to the spinal cord, sensibility in the corresponding anterior root wholly disappears.

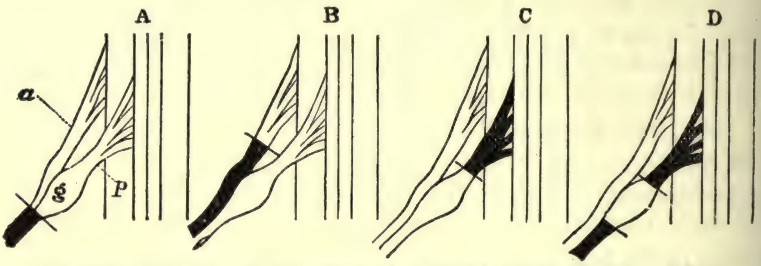

Fig. 272.—Diagram of the Roots of a Spinal Nerve, Showing Effect of Section. (Landois.)

The black represents the degenerated parts. *A*, Section of the nerve-trunk beyond the ganglion. *B*, Section of the anterior root. *C*, Section of the posterior root. *D*, Excision of the ganglion. *a*, Anterior root. *p*, Posterior root. *g*, Ganglion.

The spinal roots united, those of sensation with those of motion, constitute the *mixed spinal nerves.* They furnish the different parts of the body in which they are distributed with both sensibility and motion. Consequently the section of many spinal nerves leads to anæsthesia and paralysis of the parts innervated. In the recently cut nerves, the central as well as peripheral stumps are excitable by stimulants, the former causing pain, the latter contractions.

Ganglion.—The posterior root, before joining the anterior, has a *ganglion.* The function of this ganglion is its *trophic influence,* discovered by Waller and afterward proved by Bernard and others. When an anterior root is cut the peripheral stump becomes atrophied, whereas the central stump remains entire. The latter retains its vitality, since it is still in connection with its trophic center in the cells of the anterior horn of the gray matter.

On the contrary, when a posterior root is cut between the spinal cord and the ganglion the peripheral stump remains entire, while the central stump becomes atrophied. The ganglia of the posterior spinal roots have, therefore, the office of *trophic centers* over the sensory nerves; the trophic centers for the motor nerves lie within the cord itself and are none other than the large, multipolar cells of the anterior horns.

The *anterior roots* contain different centrifugal fibers—motor fibers, vasomotor fibers, sweat, and inhibitory fibers of the splanchnics. The motor fibers take their origin in the cells of the anterior horns, while other centrifugal fibers are united to the cerebral cortex. As to the vasomotor fibers, they have their centers of origin in the medulla oblongata and cord to penetrate the anterior roots. They probably do this without entering into communication with the cells of the anterior horns.

The *posterior* roots have centripetal reflex fibers. These leave the skin, muscles, and other organs; penetrate the spinal cord; and are in direct connection with the reflex centers located partly in the cord itself and partly in the medulla oblongata, pons, corpora quadrigemina, cerebellum, and optic thalami. The other sensory and sense fibers penetrate the cord by way of the posterior roots to ascend toward the cerebral cortex. Here are received the several conscious sensations: touch, pressure, temperature, pain, and muscular sense.

Path of Transmission of Voluntary Motion.—Voluntary motor excitation is transmitted from the cerebral cortex to the nerve-cells of the anterior horns by way of the anterior and lateral columns. These columns, as a whole, do not participate in conduction, but only the anterior pyramidal tracts of the anterior columns and the crossed pyramidal tracts of the lateral columns.

As the student knows, the crossed pyramidal tracts do not decussate in the cord, but in the medulla oblongata. The direct pyramidal tract does not decussate in the medulla, but in the spinal cord by way of the anterior commissure.

When the spinal cord is *completely severed* the voluntary movements for all of the muscles below the point of section are *absolutely abolished.*

Path of Conscious Sensations.—The sensations of touch and muscular sense are transmitted by the posterior roots and traverse the posterior columns to the brain.

Muscular sense is transmitted mainly by the *posterior columns.* The direct cerebellar tract, and probably Gowers's, also contain fibers which conduct muscle-sense to the cerebellum. Tactile and muscular sensations are abolished by locomotor ataxia.

One-sided section of the posterior and lateral columns causes: (*a*) suppression of skin sensations, or anæsthesia, in the whole half of the body innervated by nerves which enter the cord below the side of section; (*b*) loss of motion on side of section. There is very frequently observed on the side of hemisection a zone of hyperæsthesia; this is due either to removal of inhibition on that side or inflammatory irritation of the central extremity of the cut cord.

It has been shown by Woroschiloff in Ludwig's laboratory that the lateral columns are a pathway for sensory impulses. I have shown with Dr. Robert M. Smith similar results in a series of sections of the lumbar part of the spinal cord.

Section of the posterior and lateral columns does not exercise any influence upon sensibility to pain and temperature. But this is not the case when the gray matter is cut; so that it must be inferred that these impulses ascend through the gray substance to the brain.

Syringomyelia is the term applied to that condition when there is complete abolition of the conduction of *pain* and *temperature.* It is due to vacuolation of the gray matter of the cord.

FIBERS FROM THE CENTERS OF THE MEDULLA OBLONGATA.—The *vasomotor nerves,* which come from a center seated in the medulla oblongata, run down the lateral column to penetrate the gray substance and anterior roots. Hence, section of the lateral columns produces a *dilatation* of the *arterioles* innervated by vasoconstrictors, which leave the cord below the point of section.

The nerves leaving the respiratory center also run through the lateral columns and enter the gray substance, to communicate with it and leave by the anterior roots,

In the middle third of the lateral columns I have found running both *sweat* and *inhibitory fibers.* Both sets of fibers, I have discovered, decussate: the former in the spinal cord, the latter in the medulla.

Skin Reflexes.—The *most important skin reflexes* in man are:—

1. THE PLANTAR REFLEX, which is caused by tickling the sole of the foot. The involved center lies in the lumbar cord.

2. THE CREMASTERIC REFLEX.—If the skin of the upper and inner surface of the thigh in man be excited, the corresponding testicle will be seen suddenly to rise by contraction of the cremaster muscle. Its center lies between the first and second lumbar nerves.

3. THE ABDOMINAL REFLEX is a contraction of the abdominal muscles caused by a sharp push of the finger. Its center lies between the eighth and twelfth dorsal.

4. THE EPIGASTRIC REFLEX.—If the skin between the fourth, fifth, and sixth intercostal spaces be irritated, contractions of the rectus abdominis of the same side will follow. The center is between the fourth and eighth dorsal.

5. SCAPULAR REFLEX.—An irritation of the skin covering the scapulæ may cause contraction of the shoulder-muscles. Its center is between the seventh cervical and second dorsal nerves.

Tendon Reflexes.—1. ANKLE-CLONUS.—When the sole of the foot is pressed upon by the hand, then the gastrocnemius contracts, and if the pressure is continued there may be several clonic contractions. Ankle-clonus is never found in health.

2. PATELLAR REFLEX.—When a tap is made on the tendon of the quadriceps just below the patella, the foot jumps upward.

Jendrassik found that the patellar reflex could be increased if, at the time of tapping the tendon, the patient squeezed his hands together or clenched his jaws. This augmentation has been called, by Mitchell and Lewis, reinforcement of the knee-jerk. Bowditch and Warren found that if the reinforcing act preceded the blow on the patellar tendon by 0.6 second, the knee-jerk was inhibited instead of being increased. Both reinforcement and inhibition of the reflex are supposed to be due to "overflow" in the central nervous system. When the cortical motor-center for the foot of a rabbit was irritated, then the patellar reflex caused by stimulation of the paw was increased, as shown by Exner.

The knee-jerk is absent in locomotor ataxia, and exaggerated in lesions of the brain and of the lateral columns of the cord. This exaggeration is due to removal of inhibitory impulses from the brain travelling down the middle third of the lateral columns, as I have shown in the case of the ano-spinal reflex.

ANTAGONISTIC MUSCLES.—Sherrington has shown a relation to exist between the tonic condition of antagonistic muscles; for example, between the hamstrings and the vastus internus of the quadriceps extensor. Division of the hamstring muscles, or even section of their nerve, causes a great increase in the knee-jerk, elicited by tapping the patellar tendon. Stretching the hamstring muscles or weak stimulation of the central end of the cut nerve to the hamstring, abolishes the knee-jerk. Every sensory irritation which calls out a contraction of one set of muscles will inhibit the antagonistic muscles.

Sherrington has shown that the reflex arc in the knee-jerk is due to nerve-fibers passing to and from the quadriceps extensor by the anterior crural nerve, and to those passing to and from the hamstring muscles by the sciatic.

The tendon reflexes are not true reflexes, but are due to a direct stimulant action on the muscle itself. But a reflex arc is necessary to keep the muscles in a state of tonus that the tendon reflexes may take place.

Centers in the Spinal Cord.—The spinal cord presides over the movements of the *anus,* the *bladder,* and the *genital apparatus* by means of three centers located one above the other.

The *ano-spinal center* is found in the dog near the fifth lumbar vertebra. From this center emanate fibers which, with the sacral nerves, go to animate the sphincter of the anus. Irritation of this center, especially by disease, brings on spasm of the sphincter, with difficulty in passing fæces. Destruction of the center causes paralysis of the sphincter and incontinence of fæces.

In paraplegics (those affected with paralysis of the lower limbs from cord lesion), spinal incontinence or the involuntary passage of the fæces may be observed. Or there is a protracted and invincible constipation. The former condition depends upon the destruction of the spinal center, while the latter comes from paresis of the intestine in the region of the colon and rectum.

The *vesico-spinal center* in dogs is found between the third and fifth lumbar vertebra. When it is stimulated or the nerves which take their departure from it, there are energetic and painful contractions of the body and neck of the bladder.

In apoplectics there is often, first, *ischuria* (retention of urine), which seldom comes from irritative or nervous spasm of the sphincter, but more frequently from paralysis limited to the detrusor nerves only. Afterward there is *enuresis* (incontinence of urine), from paralysis also of the nerves of the sphincter.

The *genito-spinal center* is to be found in the spinal cord at the level of the fourth lumbar vertebra. If excited by stimuli it produces contractions of the lower part of the rectum, bladder, and, if the animal be a female, the uterus. In addition, if the spinal cord be cut between the dorsal and lumbar parts, tickling of the mucous membrane of the glans penis of the dog determines by reflex action an erection. Erection is no longer obtained if the lumbar cord be destroyed. Goltz and Freusburg have observed in a bitch, whose spinal cord was cut at the level of the last lumbar vertebra, the manifestations of desire, conception, gestation, delivery, and lactation to take place just as in a sound bitch.

In obstetrical wards women are delivered while in the anæsthetic sleep produced by ether, chloroform, or other anæsthetics.

These various facts show that the center of the movements of the uterus is found in the *spinal cord,* and not in the *brain.*

The sudorific centers are seated in the spinal cord. The *spinal cord* has minor *vasomotor centers* for the vessels of the parts it innervates. In fact, cutting the cord produces hyperæmia and elevation of temperature in the paralyzed parts. This is due to the paralysis of the vessels there. The constrictors are paralyzed.

Electrical excitation of the peripheral stump lowers the temperature in the parts innervated, by constricting the lumen of the corresponding arterioles. The vasomotor fibers, emanating from the spinal column, rejoin the vessels either directly, or, more commonly, by means of branches of the sympathetic.

The *cilio-spinal center* is seated in the medulla oblongata and sends fibers down the dorsal cord to the third dorsal vertebra. These fibers emerge by the anterior root of the two lower cervical and the two upper dorsal nerves and go into the cervical sympathetic to the dilating fibers of the iris. Pinching the skin of the neck will dilate the pupils: another skin reflex.

Physiology of the Medulla and its Nerves.

The *medulla oblongata,* or *bulb,* like the spinal cord, is an organ of *transmission,* or *conduction,* but at the same time it is a *center* of particular and very important functions.

Double Conduction.—Like the spinal cord, the medulla carries centripetal, or sensory actions, and centrifugal, or motor actions. The former are conveyed by means of its posterior part; the latter by the anterior part.

The centripetal, sensory conduction is crossed or decussated along the floor of the fourth ventricle. The centrifugal, motor conduction accomplishes, instead, its decussation in the *pyramids* of the medulla, where the right, lateral fibers pass to the left, and *vice versa.* This decussation of the fibers is much more complete in man than in animals. So much is this so that in man a lesion which destroys one-half of the medulla brings on complete hemiplegia of the opposite side; in animals a similar lesion never produces hemiplegia, but only paresis. Equally, in animals this same lesion does not entirely abolish sensibility in the opposite side of the body. The gray substance of the opposite side connects the parts lying over and under the lesion, and so conducts the sensory impressions.

Bulbar Nerves.—From the medulla oblongata many pairs of nerves, the *bulbar nerves,* take their origin and departure. Each nerve has a gray nucleus. The nuclei on the right side are connected with those on the left and all have their location along the gray substance of the floor of the fourth ventricle. The fibers which connect these nuclei of origin with the superior cranial centers are also crossed on the way.

Centers.—The medulla, with its gray substance and especially with the gray nuclei of the nerves which issue from it, becomes a center of very important functions.

First, it is a *respiratory center.* This center is found toward the inferior angle of the fourth ventricle, a little back of and lateral to the source of the vagi nerves. It is composed of two lateral halves, each of which, in function, can take the place of the other. This center is about two and one-half millimeters in size.

A lesion affecting *both* respiratory centers causes the sudden death of a warm-blooded animal. Therefore, this region of the fourth ventricle has been called the *vital knot.* In fact, a blow from a stick upon the back part of the head or upon the nape of the neck, also a thrust from a sharp stilleto between the back of the head and the first vertebra, suffices to cause even a large mammal to fall to the ground instantly. Butchers do this because they injure the vital knot.

COMPONENTS OF THE CENTER.—The center of respiration in the medulla is composed of an *inspiratory center* and an *expiratory center.*

From the *inspiratory center* the excitation for the nerves, and therefore for the muscles of inspiration, takes its departure rhythmically. These motor excitations always decussate in the cervical cord. The inspiratory excitation reaches the center by means of the *pneumogastric nerves,* having been carried along their sensory pulmonary fibers. The excitation is originated either by reason of an accumulation of CO_2 in the blood or the absence of O. On the contrary, an excess of oxygen in the blood abolishes excitation of the inspiratory center.

The *expiratory center,* on the other hand, gives excitation to the nerves and muscles of *forced expiration* (normal expiration is accomplished by reason of the elasticity of the thoracic case).

Experimentally it is observed that exciting the vagus nerves or their central stumps provokes very deep inspirations until the thorax stops in the inspiratory movement.

Stimulating the superior laryngeal nerves or their central stumps provokes violent and forced expirations until the thorax stops in the expiratory movement.

It is said that when a lesion affects the bilateral respiratory center there follows immediate suspension of breathing, and, therefore, death.

The medulla oblongata is a *moderating center* of the movements of the *heart.* By irritating the medulla near the originating nucleus of the vagus nerve there is caused a stoppage of the cardiac movements. The heart first slackens its systole and afterward stops in diastole. The medulla exercises this moderating action upon the heart through the vagus nerve as a medium. Some of its centrifugal fibers put themselves in relation with its inhibitory ganglia. Hence, moderation and suspension of the heart movements is obtained by irritating the peripheral stump of the vagus in the neck. According to Traube, the normal stimulus, capable of exciting this moderating action, is the accumulation of CO_2 in the blood.

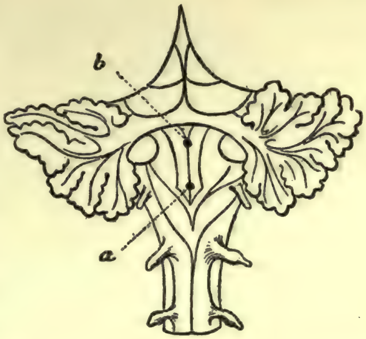

Fig. 273.—Floor of Fourth Ventricle of Rabbit. (Hedon.)

Puncture at *a*, a little above the nib of the calamus, produces diabetes. Puncture at *b* produces polyuria without glycosuria.

In the medulla is found this *moderating center,* which is antagonistic to that other center seated in the medulla oblongata: the *accelerator center* of the heart.

The medulla contains the *principal vasomotor center,* which is of the utmost importance to the economy. This general vasomotor center in the medulla may become stimulated *directly from the brain.* In short, an emotion or irritation to the cerebral cortex readily brings on ischæmia or hyperæmia either in the skin or in the internal organs. Thus, there may be pallor from fear or diarrhœa from fright.

This organ of the nervous system is a *secretory center* for the *saliva.* In the floor of the fourth ventricle at the level of the origin of the facial nerve, and somewhat posterior to it, is found the originating nucleus of the fibers of the intermediary nerve of Wrisberg. This, through the *chorda tympani* of the facial nerve, is carried to the submaxillary gland. Pricking the center or stimulating it electrically provokes a copious secretion of saliva. Certain pathological lesions may produce the same thing.

Glucose Secretion.—The puncture in the fourth ventricle should be limited superiorly by a line joining the origin of the auditory nerves, and inferiorly by one joining the origins of the vagi. This will determine within an hour the condition known as diabetes mellitus—glucose in the urine.

The diabetes ceases if the liver be extirpated, and is not produced if the liver has been previously taken away, or its vessels have been previously tied. In the liver of animals rendered diabetic in such a manner there is found an intense vasomotor paralysis.

The present theory is that the diabetic puncture produces sugar in the blood by irritation of the glyco-secretory centers in the medulla, which send fibers down the cervico-dorsal cord to the solar plexus and then in the trunk of the splanchnics to the liver-cell. It has been shown by E. Cavazzini that irritation of these nerves produces histological changes in the hepatic cells. Ligature of the aorta and portal vein, thus arresting the circulation, does not prevent these changes in the liver-cell. Irritation of the central and peripheral ends of the vagus increases the sugar in the blood. Section of the vagi causes the glycogen to leave the liver and tissues and the sugar to be absent in the blood.

The action of the medulla upon the liver is exercised by means of the spinal cord through the intervention of the great sympathetic.

The oblongata centers are: (1) *respiratory,* (2) *vasoconstrictor* and *vasodilator,* (3) *cardio-inhibitory,* (4) *cardio-accelerator,* (5) *diabetic center,* (6) *vomiting center,* (7) *deglutition,* (8) *salivation,* (9) *mastication,* and (10) *cilio-spinal.*

ANATOMY OF THE CEREBELLUM.

The cerebellum is situated at the posterior and inferior portion of the brain.

The cerebellum is entirely covered by the occipital lobes of the cerebrum in man, but only incompletely so in monkeys. It is united by the cerebellar peduncles to the cerebrum, pons, and medulla.

The *peduncles* are six in number—three on each side. They are known as the *superior, middle,* and *inferior cerebellar peduncles.*

Surface Form.—The cerebellum consists of a *median lobe* (the *vermis*) and two lateral lobes (the *cerebellar hemispheres*). The *superior vermiform process* extends from the notch on the anterior to the one on the posterior border.

The *under surface* of the cerebellum is subdivided into two lateral hemispheres by a depression (the *valley*). It extends from before backward in the median line. On the floor of the median lobe is the *inferior vermiform process.*

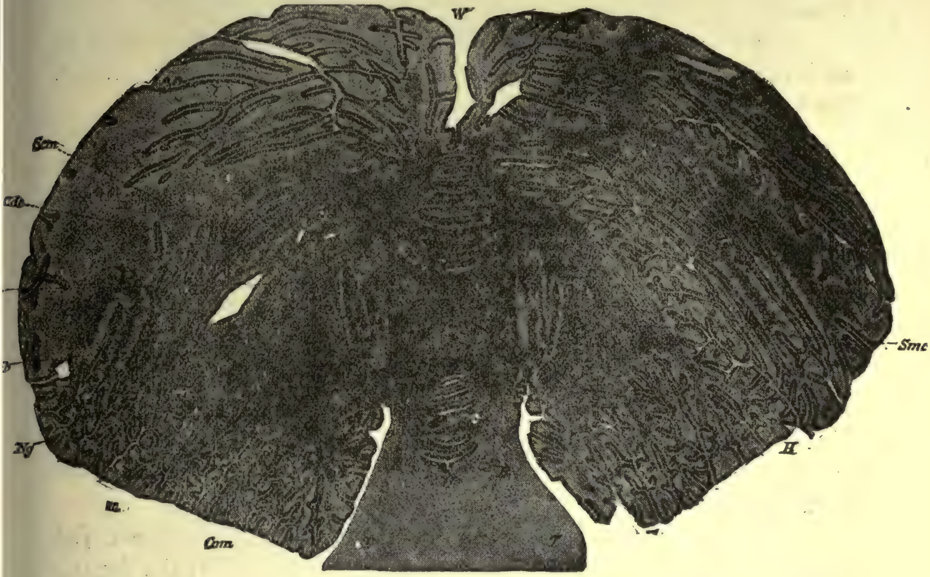

Fig. 274.—Horizontal Section Through the Cerebellum. (After B. Stilling.)

The section passes through the region under the corpora quadrigemina (*T*), then through the anterior cerebellar peduncle (*R*), and between these through the lingula (*A*). Above this lies the nucleus tegmenti, nucleus fastigii (*m*), to the left of the nucleus globosus (*Ng*), the embolus (*Emb*), and still farther to the side within the hemisphere the corpus dentatum (*Cdc*).

Internal Structure of the Cerebellum.—The cerebellum, like the spinal cord, is composed of both white and gray substances. The *gray* is the most abundant, and occupies the periphery of the organ in the form of a thin layer which is from two to three millimeters in thickness.

The *white* substance is placed in the center of the organ and is enveloped in all of its parts by the gray matter. The white represents nearly one-third of the whole cerebellar mass. Its consistency is greater than that of the gray matter.

The central nucleus of the white matter sends out an affinity of arborescent prolongations which terminate in the cells of the gray substance of the lamellæ. It is this formation which the student knows under the name of *arbor vitæ.*

Each one of the leaflike divisions of the white arbor vitæ formation is enveloped by a very thin plate of yellowish substance, while above this is the cortical gray substance. The latter sinks into the white substance at the level of the grooves which separate the plates from one another.

A *horizontal section* of the cerebellum shows in the center of each half of the organ an *ovoid body.* It is very similar to the olive of the bulb in size and structure. This is the *corpus dentatum.*

CORPUS DENTATUM.—The corpus dentatum is formed by a yellow layer folded upon itself in the form of a purse which opens in front. Within the interior of this purse is found the tissue proper of the corpus dentatum. It is formed of a matter which seems to be a mixture of the white and gray substances.

Under the name of *accessory nucleus dentatus* Meynert has described two small leaves of gray substance located in front and inward from the corpus dentatum. They are the *nucleus globosus* and *nucleus fastigii.* Stilling has discovered two clear gray nuclei at the lower border of the vermis near the median line and the roof of the fourth ventricle. He calls them the *nuclei emboliformes.* Part of the fibers of the inferior cerebellar peduncles end within these nuclei.

Hence, there are here four gray nuclei: *dentate, globosus, fastigii,* and *emboliformis.* The last three are in pairs, but the dentate is single.

The central white substance passes toward the lateral angles of the sinus rhomboideus in *three prolongations* on each side. They are the *cerebellar peduncles.*

The superior cerebellar peduncles go forward, and pass under the corpora quadrigemina, where they decussate with one another in the upper level of the cerebral peduncles. They *end* in the optic thalamus and cortex of the brain.

The middle cerebellar peduncles pass forward and inward to form the superficial annular fibers of the pons. These fibers form a true commissure between the two hemispheres of the cerebellum; other fibers decussate in the pons to terminate in the islands of gray substance; a last category ascends into the brain after decussating in the pons Varolii.

The *inferior cerebellar peduncles* (corpus restiformis) pass downward and inward to the level of the medulla, where the fibers which form them separate into three groups: the *first* form the *external arcuate fibers* of the medulla; the *second* are thrown in to the postpyramidal bodies (nuclei of Goll and Burdach); the *third* are prolonged directly into the cord under the name of *direct cerebellar tract.*

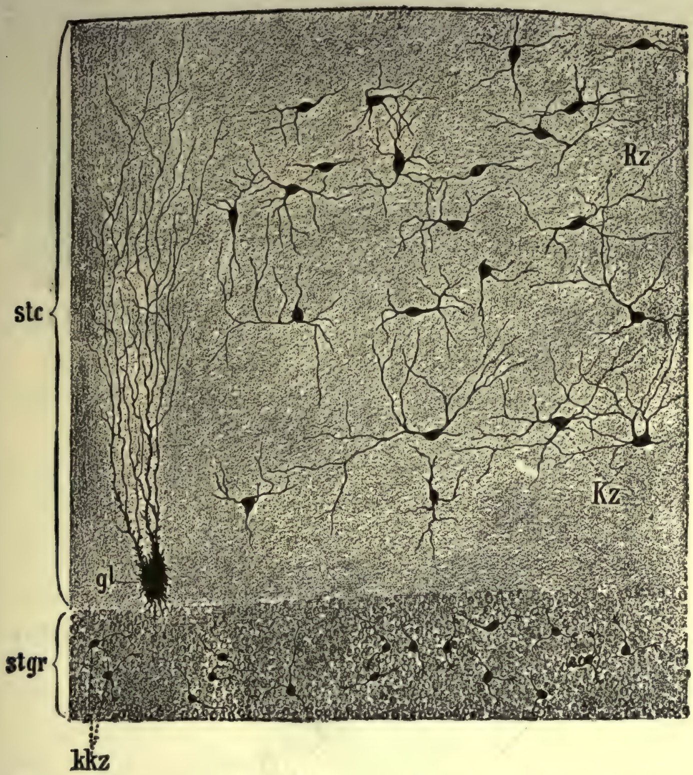

Fig. 275.—Section of Cerebellum of Man Treated by Golgi Method. (SOBOTTA.)

gl, **Glia cells of stratum cinereum.** ***Kz,*** **Basket cells.** ***kkz,*** **Small granular cells.** ***Rz,*** **Small cortical cells.** ***stc,*** **Stratum cinereum.** ***stgr,*** **Stratum granulosum.**

The cortex of the cerebellum is divided into two layers: the external, or molecular layer; and the internal granular, rust-colored, or nuclear layer. The external layer is made up of two kinds of cells: star-shaped and basket cells. The neuraxons of the stellate cells enter

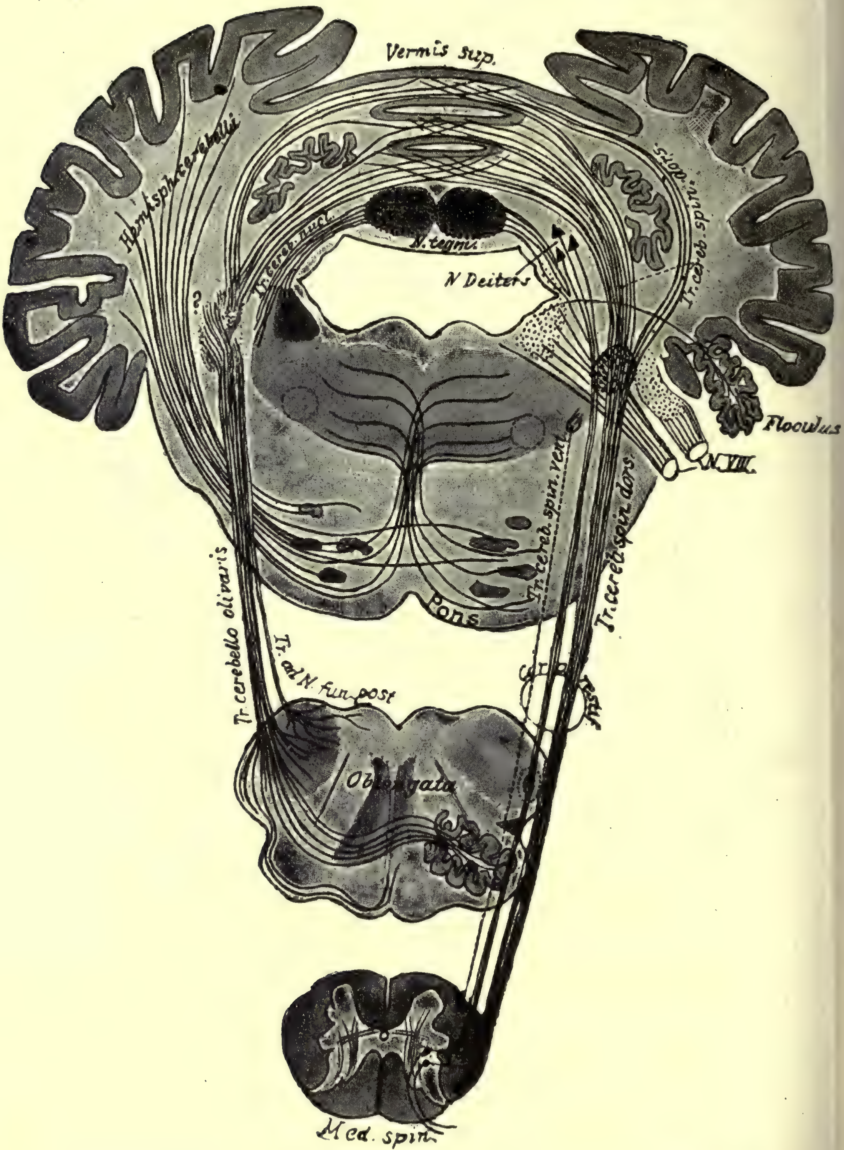
Vermis sup.
Hemisph. cerebelli
Tr. cereb. spin. dors.
Tr. cereb. nucl.
N. tegm.
N Deiters
?
Flocculus
N. VIII.
Tr. cereb. spin. vent.
Tr. cereb. spin. dors.
Tr. cerebello olivaris
Pons
Tr. ad N. fun. post
Corp. restif.
Oblongata
Med. spin.

Fig. 276.—Schema Showing the Origin and Course of the Fibers of the Peduncles of the Cerebellum. (Edinger.)

the upper part of the molecular, or external, layer, forming a network of fibers. The basket cells have their dendrons extending into the inner part of the molecular layer, while their neuraxons arborize in a tuftlike manner, forming a "basket-work" about the cells of Purkinje. The internal layer is made up of multipolar cells whose neuraxons form the horizontal fibers in the external, or molecular, layer. These horizontal fibers divide in a T-shaped manner, arborizing about the dendrons of the cells of Purkinje.

In the granular layer there are relatively large cells known as the cells of Golgi; their neuraxons end in the nuclear layer, while their dendrons lie in the molecular layer.

Between the external and the internal layers we have the cells of Purkinje, which are supposed to be the cells concerned in the preservation of equilibrium. The dendrons of the Purkinje cells occupy the chief part of the external layer, and have little, clublike projections on them. The neuraxons of the Purkinje cells go into the internal layer, enter the external layer, and arborize about the dendrons of the cells of the latter layer.

From the white matter come fibers, perhaps from the spinal cord, which on entering the granular and molecular layers have at their terminations irregular thickenings; hence called *moss-fibers* by Cajal, who believes that they conduct impulses to the granular cells.

Another kind of fiber from the white matter, perhaps from the spinal cord, goes through the granular layer into the molecular layer, and, like a climbing plant, clings around the dendrons of the cells of Purkinje, and is called the *tendril fiber*.

Foster holds that impulses from the spinal cord or other parts pass along the tendril fibers to the dendrons of the Purkinje cells and by their neuraxons away from the cerebellum to other parts. But other impulses may be carried by the *moss-fibers* to the cells of the nuclear layer. From here the impulse would be carried to the molecular layer and spread along the bifurcating fibrils a long distance, which would carry them to the dendrons of the Purkinje cells. At the same time the arborizations of the just-mentioned bifurcating fibrils running in a longitudinal direction about the basket cells would affect the Purkinje cells in an indirect manner, and, since the neuraxon of each basket cell bears baskets for several Purkinje cells, a number of these Purkinje cells would be "associated" in the same event.

The cerebellum has a threefold grasp on the cerebro-spinal axis: 1. By the direct cerebellar tract and the vestibulo-spinal tract; by the restiform bodies and inferior cerebellar peduncles. 2. By the middle cerebellar peduncles connecting the nuclei of the pons and indirectly by these nuclei with the frontal lobes. 3. By the superior cerebellar peduncles where the corpus dentatum is connected with the red nucleus and where the cerebellum is connected with the nuclei of the optic thalamus, and through new neuraxons of the optic thalamus to the parietal, ascending frontal, and ascending parietal of the opposite side. In the red nucleus we have a point of union for impulses from the cerebellum on one side, and from the cerebrum on the other side.

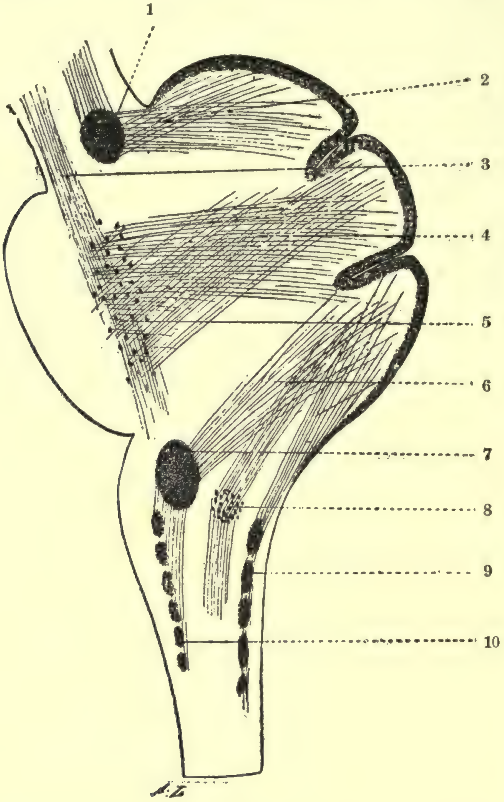

Fig. 277.—Connections of the Cerebellum with Cerebrum, Pons, and Spinal Cord. (Schema of Charpy.) (Morat.)

1, Red nucleus. 2, Superior peduncle. 3, Path from cortex to pons. 4, Middle peduncle. 5, Pontal nucleus. 6, Inferior peduncle. 7, Olive. 8, Goll and Burdach. 9, Column of Clarke. 10, Anterior horn.

PHYSIOLOGY OF THE CEREBELLUM AND MESENCEPHALON.

Cerebellum.—Mechanical irritation applied to the cortical substance of the cerebellum does not cause the animal to cry out nor are contractions of his members provoked. Even a prick or a wound that is not very deep in the cerebellar cortex does not cause any noticeable or constant disturbances, particularly in movements. More often the only movements are those of the ocular globes.

However, a deep lesion of the cerebellum—a large compression, a tumor, hæmorrhage, the removal of all or a large portion of the cerebellum—determines a peculiar ataxia which shows the *loss of equilibration.* The animal, desiring to move, shows great uncertainty, irregularity, and want of coördination of movement. Often when it wishes to take some steps, it falls backward, slipping with the feet foremost.

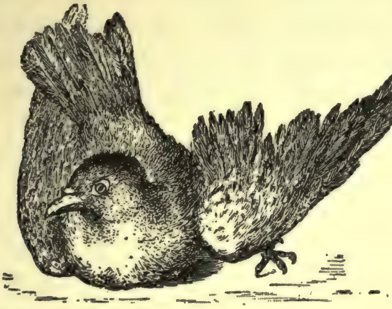

Fig. 278.—Effects of Removal of Cerebellum. (DALTON.)

The experiment succeeds best in birds. After removal of the cerebellum they can no longer keep their balance. This is known as *cerebellar tottering.* Sometimes after several efforts they succeed in remaining upon their feet for a little while, but they soon fall and always in a particular manner. They slip either with the feet spread wide apart laterally, so as to touch the ground with the breast, or else, slipping with the legs extended forward, they support themselves with the wings behind. The head is folded with more or less twisting upon the back. When these animals continue to live for some time with such a lesion they end by presenting characteristic obstructions with the feet, especially in the disposal of the toes.

A man with deep lesions of the cerebellum has very noticeably disordered movements in walking and standing erect. He cannot ballance himself well. While walking he appears like one who is drunk.

He suffers intense vertigo, with loss of balance, which renders all of his movements ataxic. This is especially so of motions of locomotion.

From this it would seem that the cerebellum is the *center of the coördination of movements.* With the cerebellum destroyed, the animal can no longer balance itself. Atrophy of one cerebellar hemisphere follows atrophy of the opposite cerebral hemisphere, showing a close relation between them.

The function of equilibration is regulated by the cerebellum, which receives afferent impulses as follows:—

1. Tactile impressions by the posterior columns to the nuclei of Goll and Burdach and from them by the restiform body to the cerebellum. To prove that tactile impressions are necessary to coördination it is simply necessary to remove the skin from a frog, when it will not be able to leap, swim, or resume its natural position when placed on its back. In locomotor ataxia, where we have a sclerosis of the posterior columns, there is great difficulty in walking.

2. Visual impressions by optic nerve conveyed by the superior cerebellar peduncle. Ataxics are able to walk much better when they fix their eyes on the ground, and when they close their eyes walking becomes impossible.

3. Muscular-sense impulse through the direct cerebellar tract by the restiform body to the vermis.

4. Impressions from the semicircular canals, which will be considered under the "Semicircular Canals." Here the vestibular nerve carries impressions from the semicircular canals by the restiform body to the nucleus fastigii and nucleus globosus of the cerebellum.

Horsley has shown that the cortex cerebelli is the afferent recipient organ, and that the cerebellar nuclei and the paracerebellar or bulbar nuclei are the efferent mechanisms of the cerebellum. The cortex cerebelli sends no direct axons via the cerebellar peduncles to the brain or spinal cord. The cortical efferent axons terminate in the intrinsic nuclei of the cerebellum, that is, the nucleus dentatus, nucleus fastigii, and nucleus emboliformis vel globosus. These intrinsic nuclei send efferent axons to the cerebral, spinal, and paracerebellar, that is, bulbar nuclei.

EFFERENT TRACTS OF THE CEREBELLUM.—An efferent tract from the cerebellum may be as follows: the fibers of the superior peduncles end in the red nucleus; the rubro-spinal tract runs from the red nucleus, decussates, passes through the medulla and pons, enters the lateral column, and terminates around the cells of the anterior horns. It is also known as Monakow's bundle. Another efferent tract may be the vestibulo-spinal tract. The nucleus fastigii of the cerebellum has neuraxons passing down to the vestibular nucleus, which is connected with Deiters, and these nuclei send neuraxons down the anterolateral columns to end in the anterior horns.

In addition to the tottering walk and vertigo, deep lesions of the cerebellum in man produce a tendency to *vomiting*. This is probably due to the irritation which spreads to the center of the origin of the vagus nerve in the underlying medulla oblongata. Sometimes there is found a disposition to dyspnœa and syncope for the same reason. Frequently there are changes in the organ of sight, as amaurosis, strabismus, and astigmatism.

MIDDLE PEDUNCLES.—Deep lesion of the middle peduncles of the cerebellum (those which pass to the pons Varolii), if made upon one side only, produces in the animal a *tendency* to *turn* or *rotate* upon the principal axis of its body. If the lesion occur in the posterior part of the peduncle the rotation is toward the side where the peduncle is cut. The animal may make as many as sixty or more revolutions per minute. The rotation will be toward the opposite side when the anterior portion of the peduncle has been injured. This rotation is explained by Schiff, who admits paralysis of the rotary muscles of the head and one side of the spinal colum.

Cutting the *middle cerebral peduncle* brings on internal strabismus in the eye on the side operated upon, but external superior strabismus in the eye upon the opposite side.

Lesion of the *inferior peduncle* of the cerebellum or of the bulb becomes painful. Also the animal falls upon the opposite side and is unable to keep itself erect. The animal's body is curved in the form of an arch toward the side of the lesion.

Lesion of the *superior peduncle* does not give characteristic and precise phenomena.

The Pons.—The pons represents a crossed way of conductibility between the periphery of the body and the brain, and *vice versa*. Besides it is a coördinating center of the actions that pass through. The pons Varolii, at its anterior surface, shows itself to be but very little or not at all irritable. Posteriorly, there are signs of great pain and agitation in the animal under stimulation. Deep irritation causes convulsions and pains according to the kind of fibers irritated. The facial nerve is often found paralyzed upon the same side as the lesion and so opposite to the paralysis of the members and trunk. This condition is spoken of as *alternate hemiplegia*.

The pons Varolii is the *center of epileptiform convulsions*. Deep irritation with electricity to the substance of the pons causes general epileptiform movements in the animal. Nothnagel, by irritating with the needle, has defined the limits of the *spasmodic territory,* or *region* of *cramps.* This *convulsive center* is irritated by excess of CO_2 in the blood, or else by absence of the proper proportion of oxygen. Oil of absinthe is capable of irritating this center.

Cerebral Peduncles.—The *cerebral peduncles* contain all of the fibers of sensation and motion in the body and direct them (except a few) toward the large ganglia at the base of the brain. *Stimulation* of a peduncle produces pain and contractions in the opposite half of the body; section or deep lesion from disease produces paralysis and anæsthesia in the opposite half of the body.

The cerebral peduncles, therefore, carry: (1) the voluntary excitations to the nerves of motion and so to the muscles; and (2) the sensitive impressions made upon the peripheral extremities of the centripetal nerves up to the brain.

I have found in the cat that mechanical irritation of the locus niger will cause the bladder to contract, indicating a high detrusor center. Mechanical irritation of any part of the brain in front of this point has no effect on the bladder.

In the greater number of unilateral lesions of the cerebral peduncle the so-called *movement in a circle* is observed. That is, the animal walks or flies, but always follows the curve of circumference. This is usually to the side opposite the lesion.

Corpora Quadrigemina.—In man atrophy of the opposite anterior quadrigeminal body follows removal of an eye. The anterior quadrigemina are also *centers for the reflex movements of the iris.* As the student already knows, the pupil contracts in the presence of strong light, but enlarges in a faint light or darkness. If the anterior quadrigeminal bodies be destroyed, the pupil remains immovable and dilated even in the presence of a strong light.

Besides these functions for the eye, the quadrigeminal bodies are believed to serve other reflex actions. The posterior quadrigeminal bodies are pathways of auditory fibers. They are also regarded as centers of coördination of movements; their destruction is accompanied by disturbances of motility.

Physiology of the Optic Thalami and Striated Bodies.

The *optic thalami,* if deeply stimulated or injured, appear to be but slightly irritable and little or not at all sensitive. The animal has shocks or shrinkings, but does not cry out. A deep lesion, made in the posterior third of the optic thalamus, determines in the animal movements in a circle from the injured side toward the sound side. If, however, the lesion be made in the anterior part of the thalamus, the circular movement is reversed.

Opinion seems to be divided as to the effect produced by lesion of the optic thalamus upon the visual function. It is concluded, however, that the surface of the thalamus (in conjunction with the corpora quadrigemina) presides over sight.

In addition to the functions just mentioned, the *optic thalami* have an influence upon the sensibility of the opposite side of the body. That is, not conscious sensibility, but that tactile and muscular sensibility necessary for the execution of extended and coördinate movements. This is especially so for locomotion without the aid of the will. These movements, then, are none else than reflex. They respond to the impressions made upon the sensory surface of the body and reflected in the large, excitomotor centers, viz., the *thalami*. The thalami are *relay centers* for the *sensory tract*.

Thus, while a normal individual walks along a clear street, perhaps he thinks of his movements but once. During that short time his *will* directs his volitional impulses; the rest of his walk, on the contrary, is executed almost automatically. In this case the excitations take their departure from impressions upon the body by the ground, space, weight of the body, etc. These impressions are all summed up in the optic thalami, from which they return, coördinated, along the nerves of motion.

When the *striated bodies* are irritated they do not provoke any signs of pain. Though the animal remains relatively quiet under ablation of the hemispheres, yet it is seized with violent and convulsive contractions in the opposite half of the body when the striated body is hardly reached. This response is especially marked in the lenticulo-striate part of the internal capsule. By stimulating a striated body with electricity, tetanus in the opposite half of the body has been obtained. The corpora striata are *motor relay centers.* They also contain a *thermogenic center.*

Experimental Physiology of Cerebral Hemispheres.

There are two great means that experimental physiology has at its disposal, viz.: *stimulation* (electrical, mechanical, chemical, and thermal) and *removal.* These are likewise applied to the most important and noble part of the nervous apparatus: the *cerebral hemispheres.* The experimental results are then compared with those observed in clinics from pathological lesions located and circumscribed in various points of the same hemispheres.

Some years ago all physiologists admitted the complete inexcitability of the cortical substance of the cerebral hemispheres. According to the view then held, mechanical, thermal, chemical, and electrical irritation of the convolutions did not determine phenomena of any kind.

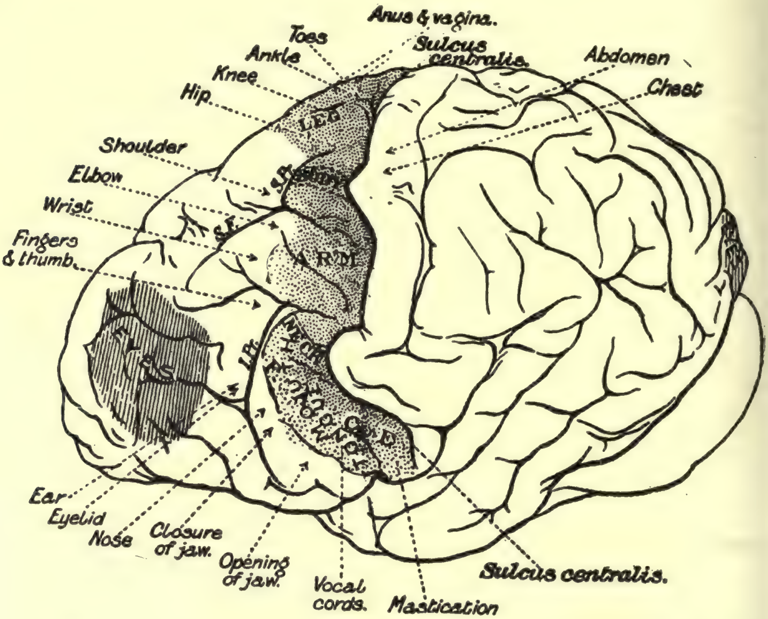
Anus & vagina.
Toes
Ankle
Knee
Hip
Sulcus centralis.
Abdomen
Chest
Shoulder
Elbow
Wrist
Fingers & thumb
LEG
S.F.
ARM
EYES
I.F.
NECK
Ear
Eyelid
Nose
Closure of jaw.
Opening of jaw.
Vocal cords.
Mastication
Sulcus centralis.

Fig. 279.—The Motor Area and its Subdivisions on the Lateral Aspect of the Hemicerebrum of the Chimpanzee. (Grünbaum and Sherrington.)

Later, however, it was demonstrated that very slight electrical currents applied to the cerebral convolutions in dogs determined various movements in the head, limbs, eyes, etc. By this means the operator can cause the execution of various movements to suit his will, as, for example, closing the fist, extending the arm, moving the leg, eyes, face-muscles, etc. These results were best demonstrated in experiments upon apes. By experiments along this line it has become feasible to fix the seat of various cortical motor centers of the brain. In man himself experiments with electricity have been made upon the convolutions exposed for various causes.

Motor and Sensory Centers.

By observations upon the chimpanzee, Sherrington and Gruenbaum have shown that the motor area is in the ascending frontal (precentral) convolution and spread over its whole length. The motor area did not, at any point, extend behind the fissure of Rolando (central fissure); on the inner side of the brain they found the motor area extended only a short distance downward, and not to the calloso-marginal fissure. In the motor area they also localized movements of the ear, nostril, palate, movements of sucking, mastication, of the vocal cords, of the thorax, abdomen, and the sphincters. The arrangement of the representation of various regions of the muscles follows the exact segmental sequence of the cranio-spinal nerve series; thus, in front of the central fissure from below upward are, first, the center of the face; next, centers for the upper extremity; next, those from the trunk; and last, for the lower extremities. Extirpation of these areas gave positive paralysis. Sherrington and Gruenbaum also found in the middle and inferior frontal convolutions a center which, when irritated, caused conjugate deviation of the eye of the opposite side.

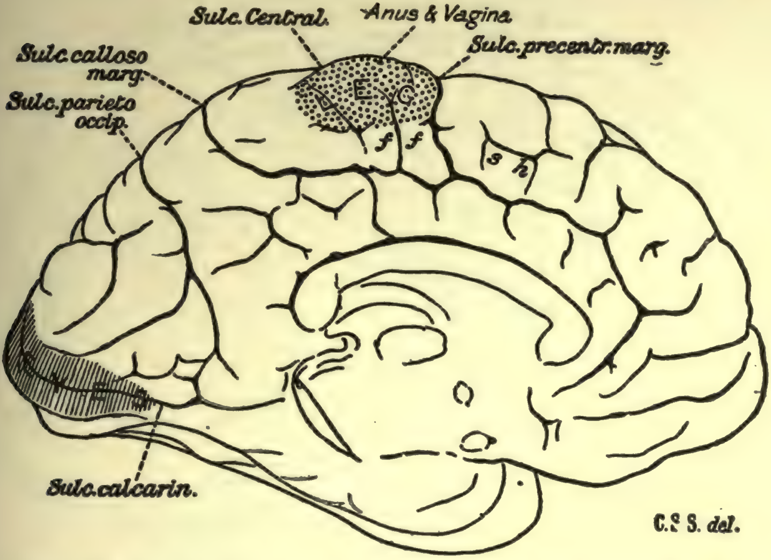

Fig. 280.—The Motor Areas and Centers on the Mesial Aspect of the Hemicerebrum of the Chimpanzee. (GRÜNBAUM and SHERRINGTON.)

In accordance with these facts of Sherrington, and from his clinical experience, Dr. Mills has located the motor centers for man mainly in the ascending frontal and the paracentral convolutions. The posterior central (ascending parietal) is for tactile sensation. Muscle-sensibility is in the superior and inferior parietal convolutions. Stereognostic perception is located in the superior parietal. On the mesial surface of the hemisphere he locates stereognostic perception in the precuneus. The center of speech is in the posterior part of inferior left frontal gyrus.

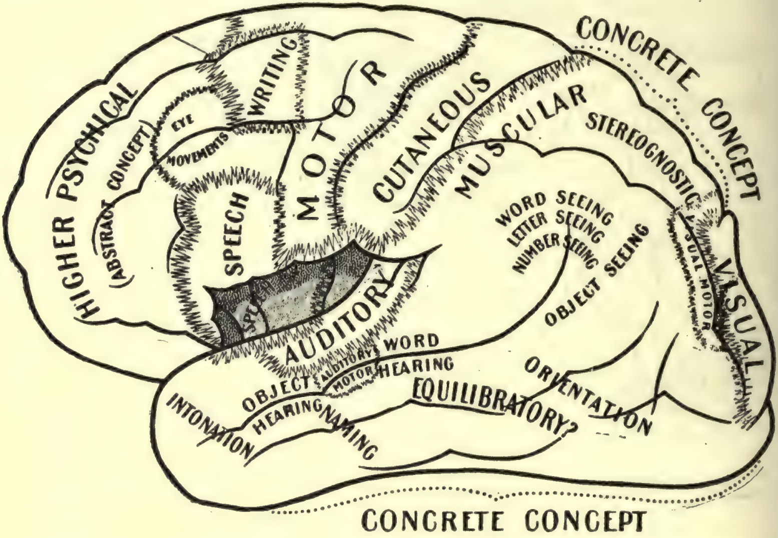
HIGHER PSYCHICAL
(ABSTRACT CONCEPT)
EYE
MOVEMENTS
WRITING
SPEECH
MOTOR
SPEECH
CUTANEOUS
MUSCULAR
CONCRETE CONCEPT
STEREOGNOSTIC
WORD SEEING
LETTER SEEING
NUMBER SEEING
OBJECT SEEING
VISUAL MOTOR
VISUAL
AUDITORY
WORD
HEARING
AUDITORY
MOTOR
OBJECT
HEARING
NAMING
INTONATION
EQUILIBRATORY?
ORIENTATION
CONCRETE CONCEPT

Fig. 281.—Areas and Centers of the Lateral Aspect of the Human Hemicerebrum. (Mills.)

In stereognosis the form of an object is recognized by tactile sensibility, although the eyes are closed. The cortical motor center for writing is seated in the base of the left frontal gyrus. There is clinical evidence to substantiate the fact that disease of the left angular gyrus may cause agraphia; for it must be remembered that, in order to write, it is absolutely essential to call to the mind memories of the words previously written. The center of taste and smell is in the uncus.

Auditory Center.—This center is seated in the first temporal convolution and in part of the second. Complete deafness is not produced in man when there is total destruction of one center, which proves that there is only a partial decussation of the auditory pathway. Irritation of the auditory centers produces movements of the ears, rotation and inclination of the head as in hearing sounds.

Visual Center.—In man, the visual center is in relation with the corresponding half of each retina. The destruction of one of these centers produces a bilateral hemianopsia, and not a total loss of vision in the opposite half of the eye. The seat of the visual center is in the cuneus. The anterior part of the visual center is in relation with the superior part of the retina; the posterior portion of the same center is in relation with the inferior part of the retina.

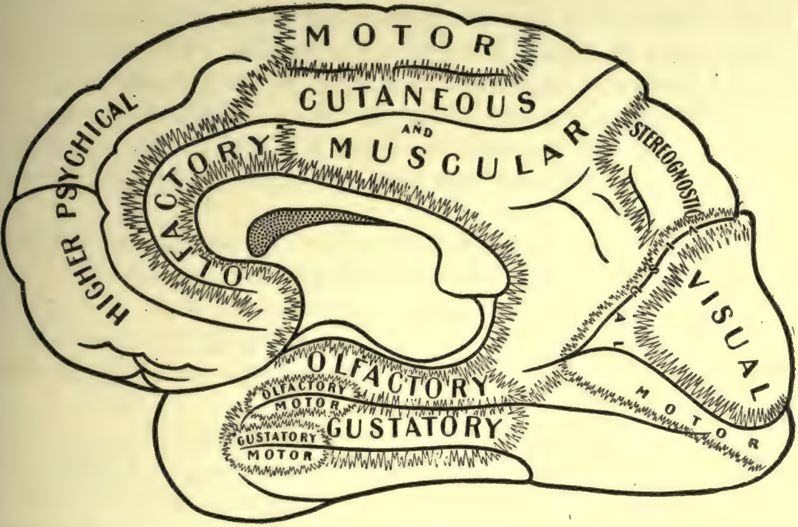

Fig. 282.—Areas and Centers of the Mesial Aspect of the Human Hemicerebrum. (MILLS.)

Irritation of the occipital lobes produces extensive movements of the eyes. Excitation of the occipital lobe always produces movements of the eyes, which are directed to the opposite side: to the left when the right occipital lobe is irritated. It is evident that the occipital lobes, whilst concerned in vision, also have efferent fibers to centers beneath the cortex. The center for the memories of objects seen is located in the right gyrus angularis. Ablation of this area produces in man mind-blindness; that is, the person fails to recall to mind the visual image of the appearance of an object, although fully seen. This condition must not be confounded with word-blindness, which is located in the left angular gyrus.

Cortical Epilepsy.[1]—Fritsch and Hitzig observed that, through continued irritation of the cortex of the cerebrum, the animal became convulsed not only in the muscles whose centers were irritated, but in all the muscles of the body. The convulsive movement always began in the muscles which were innervated by the center irritated, and then spread from this in a regular and systematic manner to the remaining muscles. For example: when an animal had the left cortical center for the eyelids irritated, the convulsive movement began in the muscles of the eyelid of the opposite side, and then spread to the other facial muscles; next, the head was bent to the right; then, first the right anterior and next the right posterior extremities were seized with convulsions; after this the convulsive movement began in the muscles of the left side and from below upwards, first the left posterior extremity, then the left anterior, and last the muscles of the left eyelid. The convulsive movements are first tonic, and then they become clonic and the animal becomes sleepy.

If an injury is produced in the motor area and the animal lives, then a spontaneous epilepsy can ensue with cortical irritation.

In the cortex of man similar results ensue from an irritation of the motor centers, except that the man usually feels conscious of the attacks in the beginning of the fit and takes care that he shall not be injured by the attack.

Cortical epilepsy can ensue from irritation of other convolutions than the motor, but these convolutions must be in a physiological association with the motor centers. The spread of the convulsive movements to different muscles can take place even after extirpation of the opposite motor area. If the motor area of a defined group of muscles is extirpated, and on an adjacent motor area another group of muscles are convulsed by an irritation, then these convulsions spread to the muscles whose motor area has been extirpated. Hence the irritation can spread to the subcortical centers and cause general convulsions, even when the original motor center which has caused the convulsions is extirpated.

Extirpation of the Motor Area.[1]—When in a dog the motor area of one hemisphere has been extirpated completely or in part, then shortly after the operation there are considerable disturbances of the movements of the opposite side. But soon the animal is able to move the muscles of the opposite side, and after a time the muscular disturbance nearly entirely disappears, except the regulation of the finer muscular movements. Quite otherwise is the result when you extirpate the motor area in apes. If you remove the whole motor area in a monkey there is a nearly complete paralysis of the muscles of arm and face, and a weakness of the muscles of the posterior extremity. There is also difficulty in moving the head to the opposite side. The weakness of the posterior extremity is not so great but that the animal can use it in walking or climbing.

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[1] Tigersted's "Physiology" has been drawn upon for the data.

If in an ape only the motor area of the finger is extirpated, then a permanent weakness in these muscles innervated by this area remains, whilst the other muscles are not affected. The result of irritation and extirpation of the cortex in the ape confirms the fact that irritation of a certain motor area always calls out movements of certain muscles, whilst extirpation of the same motor center is followed by a paralysis or weakness of the same muscles. The motor area in the ape is much more important in the muscular movements of the body than the motor area in the dog. The subcortical centers in the dog are not so much under the domination of the activity of the motor centers of the cortex as the subcortical centers in the monkey. The motor centers in man have been established (1) by irritation of the cortex, (2) by anatomical investigations, and (3) by clinical studies and pathological anatomy. The motor area in man has about the same extent as in the ape.

Flechsig's Association Areas.

Flechsig, from a study of sections of 56 human brains, has divided the cerebral cortex into 36 areas, of which 12 are myelinated before birth. He was able to determine these areas by the fact that in the cerebral cortex the fibers take on myelin at different periods, and thus he is enabled to track the fibers. The sensory tracts of the central nervous system take on myelin before birth. The motor tract receives its myelin after birth, but in the spinal nerve roots the anterior are myelinated before the posterior. The first areas to become myelinated are the sense areas—smell, touch, muscle-sense, sight, hearing, and taste. The next series of centers to become medullated have at first only fibers within themselves—that is, neither projection fibers nor association fibers—and Flechsig denominates them automatic centers whose function is unknown. The rest of the areas have association bands, and it is most interesting to note that the earlier areas of this group develop as marginal zones around the primary sensory areas and first receive short fibers from them. They are without doubt connected with sensory areas in function. The six sense areas in the cortex, namely, those of smell, touch, muscle-sense, sight, taste, and hearing, are proportional in size to the nerve or nerves supplying them. For example, the tactile and muscle sense area is greatest, while the visual area is larger than the auditory. The structure of each area corresponds to the structure of the sense organ. Thus the visual area has many layers of cells, thus corresponding to the many layers in the retina. The olfactory area has the fewest layers, thus being in agreement with the cells of the olfactory mucous membrane. The area for hearing in the cortex is twice as thick there as in the rest of the temporal convolution. Hence each area is to be considered as a repetition, in the cortex, of a peripheral sense organ. Flechsig suggests the name of projection fields for the seven primary sense areas.

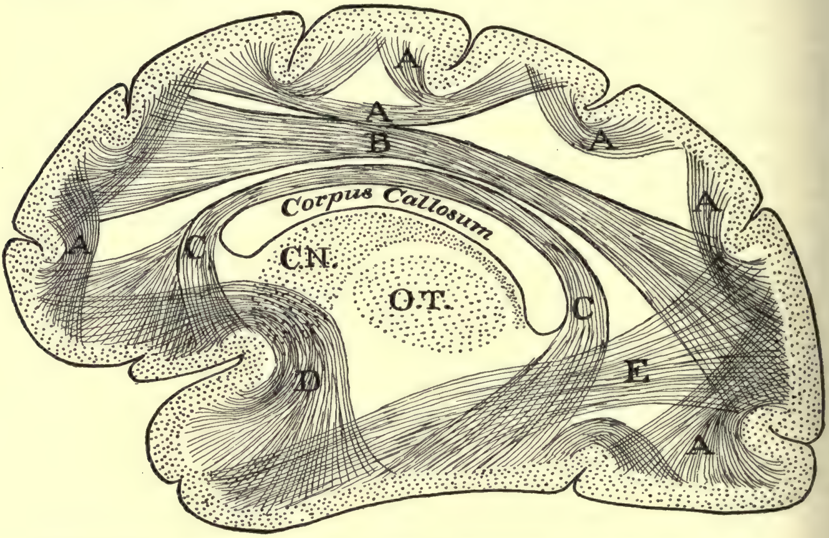

Fig. 283.—Lateral View of a Human Hemisphere, Showing the Bundles of Association Fibers. (STARR.)

A, *A*, Between adjacent gyri. *B*, Between frontal and occipital areas. *C*, Between frontal and temporal areas, cingulum. *D*, Between frontal and temporal areas, fasciculus uncinatus. *E*, Between occipital and temporal areas, fasciculus longitudinalis inferior. *C*, *N*, Caudate nucleus. *O*, *T*, Optic thalamus.

As to the great sense area for touch and muscle sense, it is found that the sensory paths for the legs are the first to reach the cortex, and end in the paracentral lobule at the upper third of the ascending parietal convolution, extending on to the posterior surface of the ascending frontal convolution. The corresponding motor tract develops from the area of large pyramidal cells in the ascending frontal convolution. Thus the sensory and motor areas in the brain are not mixed, except in the fissure of Rolando.

The experiments of Sherrington and Grünbaum on the chimpanzee are in accord with the results of Flechsig. They found the motor centers to be in the ascending frontal convolution, separate from the sensory centers of touch and muscle-sense in the ascending parietal convolution. Around each primary sense area develops a border zone of association centers.

Only about one-third of the brain is composed of sensory and motor areas; the question arises, "What is the function of the other two-thirds?" The fibers going to the latent, inexcitable area of the brain take on myelin much later than those of the excitable area. The fibers in this latent area do not run downward like the projection fibers, but run in a more or less longitudinal direction, and are known as internuncial or association fibers; they are of both a centrifugal and centripetal nature. These internuncial fibers connect the latent cortex with the excitable cortex. According to Flechsig there are three association centers: (1) the frontal, (2) the parieto-occipito-temporal, and (3) the insular. These centers are centers to receive impressions, and are the seat of memory. The internuncial fibers are: (1) the superior longitudinal bundle uniting the Rolandic and parieto-occipital region; (2) the perpendicular bundle passing between the parietal lobule and the temporo-occipital region; (3) the anterior association bundle connecting the frontal and temporal lobes and traversing the bottom of the sylvian fissure; and (4) the inferior association bundle uniting the temporal and occipital lobes. The frontal association center is in front of the ascending frontal convolution; the insular, or middle, association center is the cortex of the island of Reil; whilst the parieto-occipito-temporal association center is situated back of the ascending parietal convolution.

The anterior association center, or frontal, is made up of the anterior half of the first and a great part of the second frontal convolution. The middle association center or insular is covered by the insula, whilst the posterior or parieto-occipito-temporal is made up of the præcuneus, the parietal convolution, the second and third temporal, and the anterior part of all three occipitals. Disease of the anterior association center, as in idiocy and dementia, changes the character; a man of good and orderly habits becomes irritable and disorderly, and loses his sense of morality; there is a loss of ideas regarding his own personality, and his relations to what is taking place inside and outside his body. He considers himself enormously wealthy, or a genius, or he may fail to recognize his own surroundings, and perform acts not reconcilable; in other words, he is like one with paresis. When disease attacks the posterior association centers he is unable to name correctly objects which he can touch and see, or, if both centers are affected, he may not at all recognize the nature of these objects, so that he loses the power of forming intelligent conceptions of the world around him. He is bankrupt in ideas, although his affections may not be altered. In other words, he has what is called mind-blindness. The posterior association center is highly developed in musicians.

PHENOMENA FOLLOWING THE DESTRUCTION OF ONE OR BOTH OF THE CEREBRAL HEMISPHERES.

Ablation of the cerebral hemispheres is generally performed in frogs or fowls, who seem to endure the operation sufficiently well. Mammals easily succumb.

The skin of the head being cut and the thin cap of the skull removed, the brain is reached. The incision of the meninges is painful, but, after gradually removing the mass of the hemispheres from above downward, the bird shows itself indifferent. In fact, it becomes more stupid and apathetic as more of the cerebral tissue is removed. When the removal of the hemispheres is completed without injuring the peduncular system, with its ganglia, and the hæmorrhage stopped as well as possible, the bird remains in a sleepy state. It has a tendency to bury its head and close its eyes; it breathes slowly, but does not walk away.

Under stimulation the bird reopens its eyes, raises its head, takes a few steps, then suddenly returns to its former position.

The bird, having recovered from its traumatism, the following phenomena are observed within a few days: The bird has become an *automaton.* It does not eat, so that it becomes necessary to put the food into its mouth. It moves not at all of its own volition; if pursued it takes some steps; its pupils contract under the influence of the light; it cries or tries to flee when the skin is irritated. It is startled by loud noises. For the rest there are no longer voluntary movements, and the few movements observed are aroused by external excitement, or some internal need. The movements are rubbing the skin with the beak, scratching the head with the foot, etc.

The *vegetative functions* (once that care is taken to nourish the birds and clean them) are performed without disturbances. If the bird lives for some time it shows a *general deposit of fat.* The skin and muscles in particular are seen to be infiltrated with adipose tissue.

In these birds there are only movements of a reflex nature.

Sensibility is blunted since the stimuli are not able to reach the cortical centers. Hence, they cannot provoke volitional acts in them. As Küss says, these birds live, but do not *perceive;* they hear, but do not *listen;* they are aware of stimuli upon the tongue, but do not *taste them.* They are just as a human being who is asleep or absorbed in contemplation. He may drive a fly from the face without being conscious of it.

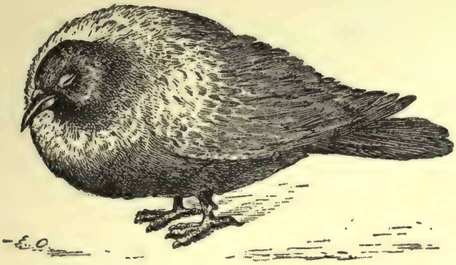

Fig. 284.—Effects of Ablation of Cerebrum. (DALTON.)

When *but one* cerebral hemisphere is removed without in the least injuring the other and the animal recovers, it does not show positive disturbances of intelligence or of conscious sensibility or of voluntary motion. However, the opposite side shows weakness. Should the lesion extend to the underlying basal ganglia or to the peduncular system, there will be *complete hemiplegia* in the opposite side of the body.

The same manifestations are observed in a man who has lost an entire hemisphere from a wound or from disease. There is no positive lesion of intelligence, but there is manifested very marked fatigue from intellectual labors. If the lesion has extended toward the peduncular base of the hemisphere, there is hemiplegia in the opposite side of the body.

The crowbar case is a much-cited instance. A workman twenty-five years of age was engaged in charging a blast in a rock. The instrument he used was a sharp-pointed bar, forty inches long, one and one-quarter inches in diameter and weighing twelve pounds. The charge was suddenly exploded, driving the bar so that it entered the man's lower jaw and came out at the top of the head close to the sagittal suture in the frontal region. It fell at some distance, covered with blood and brains. For the moment the victim remained unconscious. An hour after the accident he walked to the house of a surgeon, where he gave an intelligent account of the accident. For a long time his life was despaired of, but he finally recovered to live twelve and one-half years longer.

It may be concluded, therefore, that one cerebral hemisphere only is sufficient for the mobility and sensibility of the two sides of the body, as well as the performance of psychical functions. The individual with one hemisphere destroyed remains like one who has lost an eye. That is to say, the brain continues to perform its functions, animal as well as psychical, but with *noticeable weakness, greater effort, and fatigue.* The frontal lobes are the chief seat of the will, of the memory, and intellectual functions.

The *irritability* of the cerebral cortex may be diminished or exaggerated by various circumstances. Thus, opium, ether, chloroform, chloral, the bromides, cold, asphyxia, etc., diminish it. Inflammation, urea, uric acid, atropine, strychnine, etc., increase its excitability.

Action of Brain Extracts.—In 1898 I found that infusions of dried brain reduced the heart's frequency and the arterial tension. Section of the vagus or its paralysis by atropine did not prevent this action. Halliburton did not obtain the same results after the use of atropine, but my experiments have been confirmed by Swale Vincent and Sheen. Quite recently Swale Vincent and Cramer have found two substances in brain, both depressing the heart even after the previous use of atropine. They also obtained another substance depressing the circulation, but its effects are abolished by atropine.

SLEEP.

Sleep is characterized by a suspension of consciousness, a diminution of reflex activity of the nerve-centers, a decrease of the excitability of the nerves, and a lessening in all the chief functions of the body. The activity of the cerebral motor centers is nearly suspended in the majority of animals as they seek a reclining position.

In extreme fatigue sleep is preceded by yawns, a want of attention, a decrease of sensibility in the special senses, a progressive loss of movement, and a dropping of the upper eyelids. The eyes are closed, vision is necessarily then abolished. The pupil is contracted, the eyeball is turned upward and inward; at the same time hearing disappears and consciousness vanishes. During sleep the metabolic processes of nutrition are slowed, and there is a diminution of the heart-beats, of the arterial tension, and of the movements of respiration. Sleep is deepest during the first one and one-half hours; after that its depth greatly diminishes. Durham was the first to show that during sleep the brain is anæmic, but it is only an epiphenomenon, and not the cause of sleep. Plethysmographic tests of the arm in a sleeping person show a decrease of volume whenever the subject is disturbed, although the noise may not be sufficient to wake him.

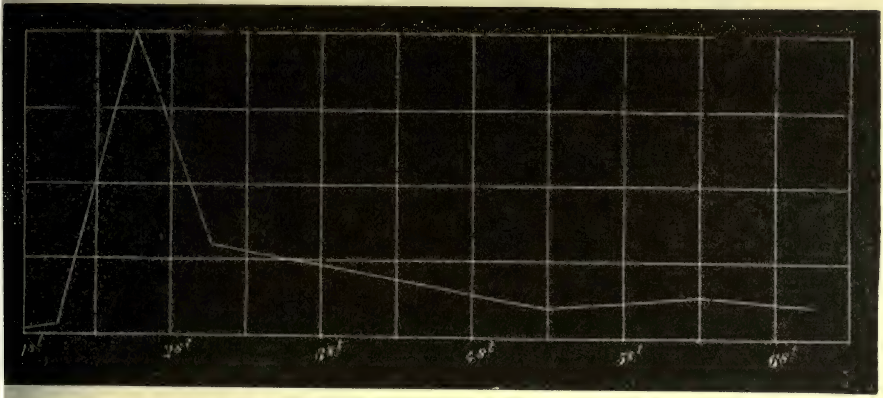

Fig. 285.—Curve of the Depth of Sleep. (PIESBERGEN.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Read from left to right.

This means that the brain is anæmic during sleep, and that the blood-supply of the brain is increased upon waking.

The histological theory of Demoor is that during sleep the dendrons are retracted and break the connections between the dendrons and arborizations which are necessary for the action of the nerve-centers. Demoor found that in deep anæsthesia there were moniliform varicosities on the dendrons. The chemical theory is that during wakefulness certain fatigue-products (lactic acid, etc.) are generated, which have a somnolent effect upon the brain. If the blood of an exhausted dog is transfused into a dog awake, it will cause him to be fatigued. It is probable that the fatigue of the brain-cells, the law of periodicity of the action of the nerve centers, and a decrease of external stimuli are the main causes of sleep. The intimate cause is not known.

That the absence of sensory impulse has an important action in promoting sleep is shown by the case of a boy who had only one eye and one ear to keep him in touch with the external world. All other avenues of sensory impulses were abolished. If now, these avenues of impulse were abolished by bandaging the ear and eye, the boy would fall asleep. If a dog is kept awake five days he will die. This wakefulness is attended with a lowering of temperature (8° C.), diminished reflex activity, and changes in the brain. In man, loss of sleep causes a slight increase in weight. The excretion of nitrogen, and especially that of phosphoric acid, is increased by the want of sleep; acuteness of vision is also increased. But when the man is permitted to make up for this loss of sleep, there is a complete disappearance of the just-mentioned conditions and a normal state ensues.

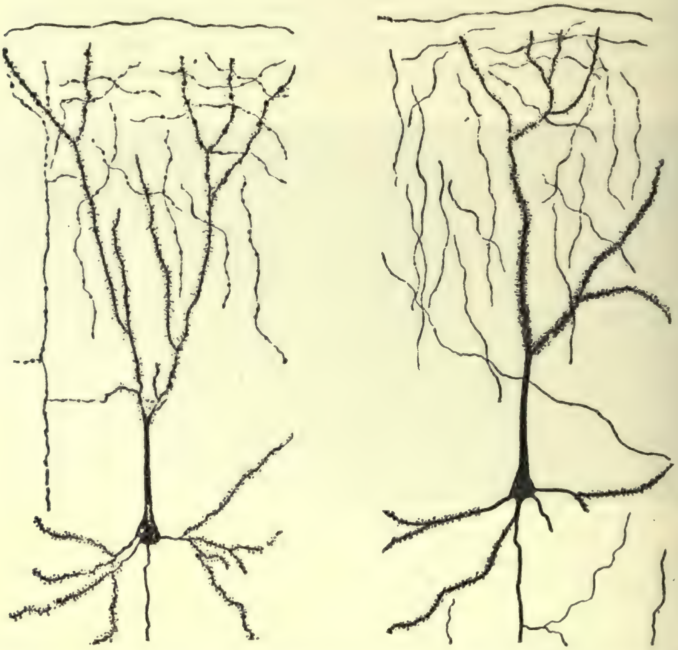

Fig. 286.—Pyramidal Cells of the Marmot in Two Different Conditions. (After Querton.)

On the left, pyramidal cell of the marmot asleep; on the right, that of the marmot awake.

NARCOTICS.

Meyer and Overton have arrived at the conclusion that anæsthesia is caused by the solution of the lipoid (fatty) constituents of the cells by the absorbed anæsthetic. All the substances which dissolve fats are anæsthetics if they enter the cell, and anæsthetic power is proportional to this factor. The quick recovery which ensues when the anæsthetic substances are removed shows that the lipoids are not taken out of the cell, but merely dissolved within the cell. Wright finds that anæsthetics produce a disappearance of Nissl corpuscles and a shrinkage of the nerve-cells after prolonged anæsthesia by either chloroform or ether.

Bromides and opium produce sleep by depressing the excitability of the cortex cells of the cerebrum.

CEREBRO-SPINAL FLUID.

The cerebro-spinal fluid is like a lymph-fluid. It is only in the smallest part a transudate, and as such is modified through the specific secretion of the capillaries of the brain. It is chiefly a specific product of the brain. It has been shown that this fluid contains 20 to 30 per cent. of potash salts and only 15 per cent. of soda salts, and the brain has also an excess of potash compared with sodium. Spina believes that the cerebro-spinal fluid comes either from its blood-vessels or the brain-substance, and not only from its choroid plexus. It differs from the blood-plasma in containing only 0.2 per cent. of albumin, whilst blood contains 7 per cent. and lymph 4.5 per cent. of albumin. Cerebro-spinal fluid does not contain, like the blood, an agglutinin (it has no globucidal action on foreign blood), nor an alexin.

According to Allihin, it contains 0.0461 per cent. of glucose, 0.221 per cent. of proteid, 0.2794 per cent. of organic material, 0.813 per cent. of inorganic, 98.886 per cent. of water; peptones and albumoses were not present, and the proteid seemed to be a globulin.

The cerebro-spinal fluid of diseased brains contains poisonous material, which results from a disintegration of nervous tissues. In general paralysis of the insane, Halliburton and Mott found a nucleo-proteid in the cerebro-spinal fluid. It is a nucleo-proteid, which, when injected into the circulation, can cause intravascular clotting. The cerebro-spinal fluid and the blood also contain choline, which depresses the heart. Donath injected choline into the sensori-motor convolution and produced convulsive attacks. Choline is also found in other diseases of the central nervous system.

Ether and pilocarpin increase flow of cerebro-spinal fluid, whilst atropine slows it, and amyl nitrite has no particular effect. Medicines, as a rule, and the toxins of bacteria, do not appear in the cerebro-spinal fluid when given by the mouth or subcutaneously. Strychnia injected into the cerebro-spinal fluid has a very intense action, as much as when ten times that quantity is injected into the blood. Cocaine injected into the cerebro-spinal fluid causes an anæsthesia in the lower extremities, lasting forty-five minutes. Whilst chemical substances with difficulty appear in the lymph when injected into the blood, they appear quite readily in the blood when injected into the lymph-tracts.

REACTION-TIME.

When a terminal organ of special sense is irritated, the time between this stimulation and the moment when motion ensues as the result of conscious perception of the irritation is called reaction-time. Müller's law of specific energy of sensory nerves is that irritation of nerves of special sense always causes sensations of the same kind. Thus, when the nerve of hearing is irritated by different agents, it always gives rise to a sensation of sound. Perception-time is the time required, for example, in colors, to decide what color it is and in what part of the visual field it is located. The organs of special sense differ from each other as to the number of separate excitations that they can receive in a second. In reaction-time by the auditory nerve the following things are involved: (1) the time consumed in sound reaching the ear; (2) the time taken for the reception of the stimulus by the sensory terminals of the auditory nerve and the transmission to the higher centers, so that volitional impulse may be started in the cerebral motor centers; (3) the time for the conveyance of those motor impulses to the nerve-cells of the spinal cord; (4) the time necessary for the generation of impulses in the cells and their transit down the motor nerves to the muscles of the hand; (5) the latent period of the contraction of those muscles. The reaction-time for sound is about 0.150 second; light, 0.195 second; and for touch, 0.145 second. Perception-time varies from about .01 to .02 second.

THE GREAT SYMPATHETIC.

The ganglia lying on each side of the vertebral column may be divided into four parts, viz.: cervical, thoracic, abdominal, and pelvic.

The cervical part of the great sympathetic is composed of three ganglia.

The thoracic portion is composed of twelve ganglia.

The abdominal, or lumbar, part consists of four ganglia.

The pelvic portion consists of five or six ganglia, including the coccygeal ganglion.

Two structures only finally receive the sympathetic fibers; that is, involuntary muscular tissue and secretory epithelium.

SYMPATHETIC NERVOUS SYSTEM.

The ganglia lying on each side of the vertebral column are lateral or vertebral ganglia. The prevertebral collateral ganglia are the ganglia in advance of the vertebræ, as the semilunar, inferior mesenteric, etc. From the prevertebral ganglia, nerves go to the terminal ganglia in the tissues.

The efferent fibers of the sympathetic nervous system arise in the intermedio-lateral column of gray cells. They pass out by the anterior root from the spinal cord. From here they go by the white ramus to a sympathetic ganglion. From the sympathetic ganglion they may pass in two directions: (1) they may form synapses about these cells, and from these cells new axons (postganglionic fibers) may arise and pass outwards in the visceral nerves, or back, through the gray ramus connected to the ganglion, into the spinal or somatic nerve to the blood-vessels as vasomotor nerves, or sweat-glands as secretory nerves, or to hairs as pilomotor nerves; (2) or they may pass through the ganglion on to one situated more towards the periphery, in which they form synapses and are continued onward by new axons. These ganglia from which they do not pass back to somatic nerves are called the prevertebral or collateral ganglia. These nervous fibers, after their interruption, proceed as gray nonmedullated fibers to their termination, where they break up into a network of anastomosing fibers, with cells or a sort of terminal ganglion. When sympathetic nerve-fibers are interrupted in a ganglion, the fibers, before they meet the ganglia, are preganglionic; after they leave the ganglion, postganglionic. The number of nerves leaving a ganglion is greater than the number of nerves entering it. If the sympathetic fibers pass through the vertebral ganglia to be interrupted in the prevertebral ganglia, then they are preganglionic, and the fibers leaving the prevertebral ganglia are postganglonic. By nicotine it can be determined if fibers end in a ganglion or pass through it, for nicotine paralyzes the preganglionic terminals of the nerve-cells of a ganglion, or, according to Langley, a special receptive substance in the nerve-cell.

Langley calls the sympathetic system an autonomic system, because it is a sort of independent system from the central nervous system.

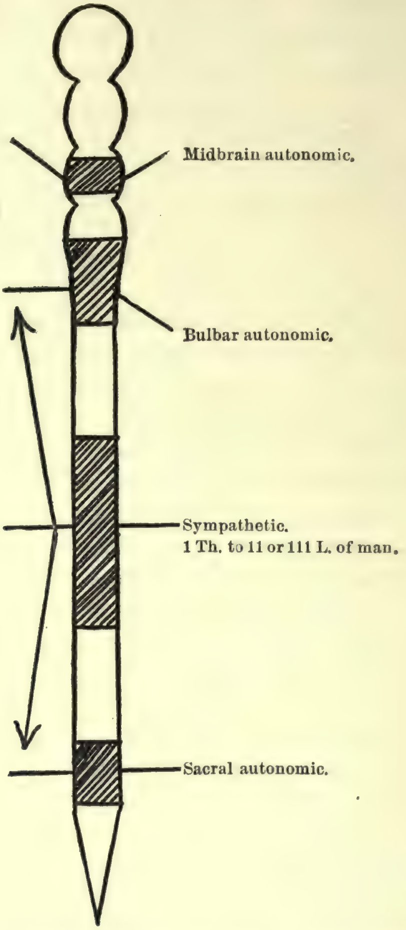
Midbrain autonomic.
Bulbar autonomic.
Sympathetic.
1 Th. to 11 or 111 L. of man.
Sacral autonomic.

Fig. 287.—Diagram of the Origin, in Man, of the Efferent Autonomic Fibers from the Central Nervous System. (LANGLEY.)

The sympathetic system proper arises from the dorso-lumbar cord.

The cranial and sacral autonomic systems have more in common with one another than either has with the sympathetic, and on this account they may be grouped together as the parasympathetic system. The parasympathetic system includes the midbrain autonomic

—bulbar autonomic—and sacral autonomic systems. The fibers from the midbrain arise in it, and go out in the third nerve and by the short ciliary nerves to the sphincter of the iris and the ciliary muscles, and cause their contraction. The fibers arising in the bulb travel through the facial, glosso-pharyngeal, vagus, and the spinal accessory.

Cranial Ganglia.

The ciliary ganglion of the fifth cranial nerve has preganglionic sympathetic fibers from the motor oculi by a short root which arborize about the ganglionic cells and when irritated contract the pupil. The postganglionic fibers of this ganglion start from the superior cervical ganglion through the ciliary ganglion to contract the blood-vessels of the iris and retina.

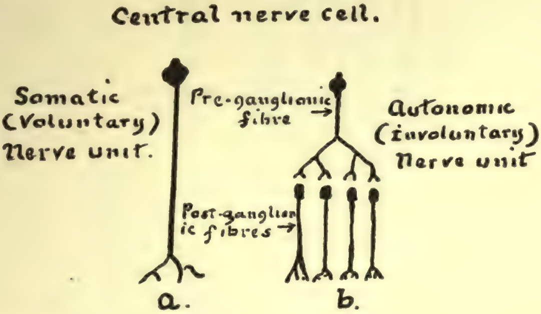
Central nerve cell.
Somatic (Voluntary) Nerve unit.
Pre-ganglionic fibre
Autonomic (involuntary) Nerve unit
Post-ganglionic fibres
a.
b.

Fig. 288. (LANGLEY.)

The number of fibers leaving a ganglion is greater than the number of fibers entering it. This is due to the fact that the preganglionic fibers divide.

The spheno-palatine ganglion of the fifth cranial nerve obtains its preganglionic fibers from the facial. Its nerve-cells send postganglionic fibers to the blood-vessels and glands of the mouth and nose. Stimulation of this ganglion dilates the blood-vessels and augments secretion.

The otic ganglion of the fifth cranial nerve obtains its preganglionic fibers from the ninth nerve by the pathway of Jacobson's nerve and the small petrosal. The postganglionic fibers run in the auriculo-temporal of the fifth, to increase the secretion of the parotid gland and to dilate the blood-vessels.

The submaxillary and the sublingual ganglia acquire their preganglionic fibers from the chorda tympani of the facial. Their postganglionic fibers dilate the blood-vessels and increase the secretions of these glands.

As to the bulbar origin, the autonomic efferent fibers of the vagus end in the cardiac ganglia, from which postganglionic fibers run to the cardiac muscle. In its course the vagus meets small groups of nerve-cells in the lungs, the external wall of the œsophagus, and the stomach.

The vagus sends many fibers to the (enteric nervous system) Meissner-Auerbach ganglia in the stomach, furnishing secretory nerves to the stomach and pancreas; and the number of its fibers in its downward course to the intestine diminish, and are completely absent in the descending colon. The bulbar autonomic system innervates the upper part of the digestive tract, from the mouth to the descending colon, and the cavities and organs in connection, as the salivary glands, the lungs, the liver, and the pancreas. The sacral autonomic nerves innervate the lower part of the digestive tract, the descending colon, anus, bladder, and, by their nervi erigentes, the external genitals. The sphincter of the iris and ciliary muscle receives no fibers from the spinal thoracic sympathetic, but only cranial autonomic nerves. The bulbar and sacral autonomic systems are independent of the spinal thoracic sympathetic system as regards development, and are not a part of the spinal sympathetic system.

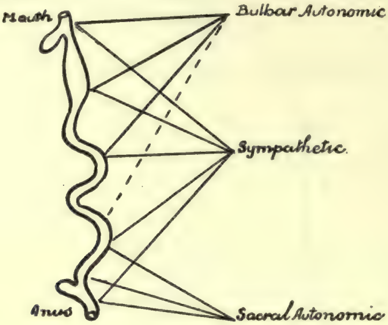

Fig. 289.—Diagram of the Main Distribution of the Bulbar and Sacral Autonomic Fibers. (Langley.)

The bulbar fibers supply the anterior end of alimentary canal and the salivary glands. The sacral fibers supply the posterior end of the alimentary canal and the external generative organs. The sympathetic supplies the whole tract and also the skin and the internal generative organs which receive no involuntary fibers from any other source.

A long series of fibers arise from the thoracic and upper lumbar spinal cord. These are the fibers of the sympathetic nervous system.

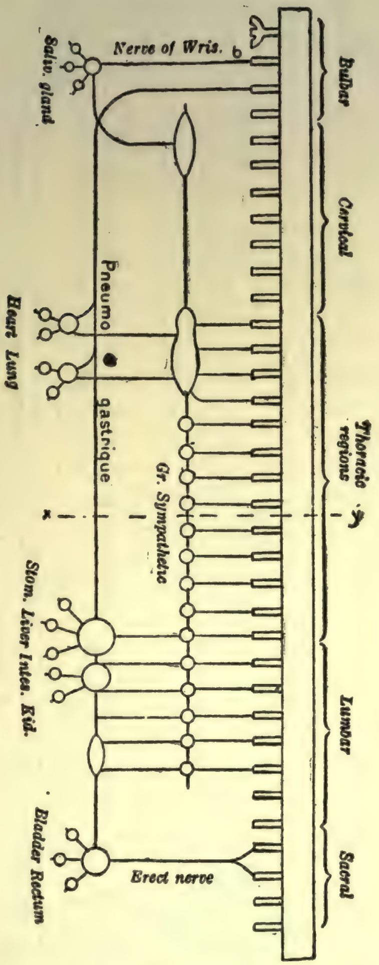
Nerve of Wris.
b
Saliv. gland
Bulbar
Cervical
Pneumo
gastrique
Heart Lung
Thoracic regions
Gr. Sympathetic
x
y
Stom. Liver Intes. Kid.
Lumbar
Sacral
Erect nerve
Bladder Rectum

Fig. 290.—Diagram of the Great Sympathetic, Representing its Visceral Distribution. (MORAT.)

On the right, medulla oblongata, spinal cord, and roots. In the middle, vertebral chain and ganglia; on the left, second chain (prevertebral) formed by the pneumogastric nerve and the mesenteric nerves, solar plexus and hypogastric plexus. On the extreme left, terminal ganglia and plexuses of the viscera. The break between the peripheral and deep neurons is effected either in the catenary, terminal or intermediate ganglia. Symmetrical with regard to a plane, *xy*, which intersects the thorax. Principal condensed origins in the thoracic region. Supplementary origins arising from the medulla oblongata (nerve of Wrisberg and pneumogastric) and from the sacral spinal cord (erector nerves).

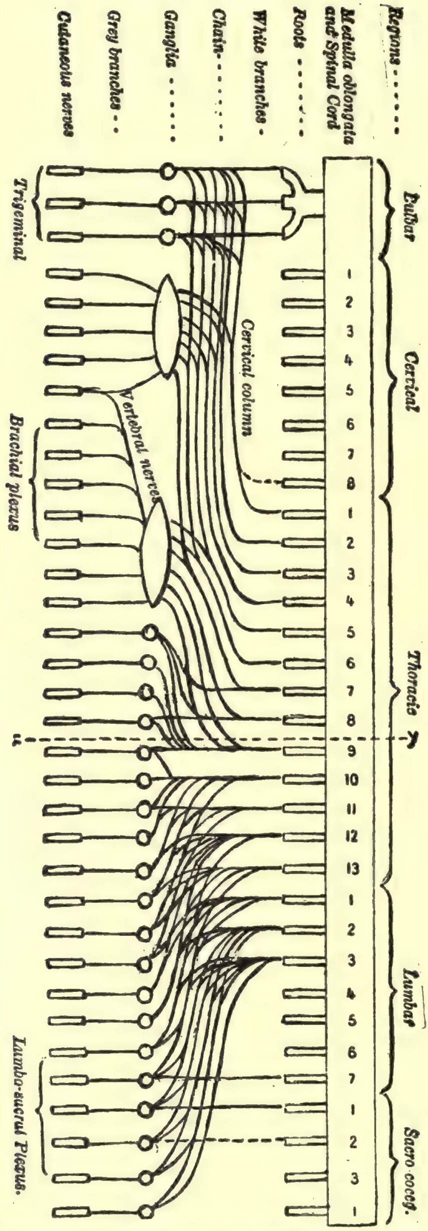
Regions
Medulla oblongata and Spinal Cord
Roots
White branches
Chain
Ganglia
Grey branches
Cutaneous nerves
Bulbar
Cervical
Thoracic
Lumbar
Sacro cocc.
Trigeminal
Brachial plexus
Lumbo-sacral Plexus
Cervical column
Vertebral nerves
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
5
6
7
1
2
3
1

Fig. 291.—Diagram of the Great Sympathetic, Representing its Cutaneous Distribution and its Two Orders of Fibers of Projection. (Morat.)

On the right of the diagram, the medulla oblongata, the spinal cord and their roots; on the left the cutaneous nerves, containing those roots (chosen

The chief difference between the sympathetic and the parasympathetic systems is that the former sends nerve-fibers to all parts of the body, whilst the latter sends fibers only to certain parts. According to Langley, when a tissue has a double innervation the effect produced by one set of fibers is, in most cases, the opposite of the main effect produced by the other set of fibers. Thus; if one set causes mainly contraction, the other causes mainly inhibition.

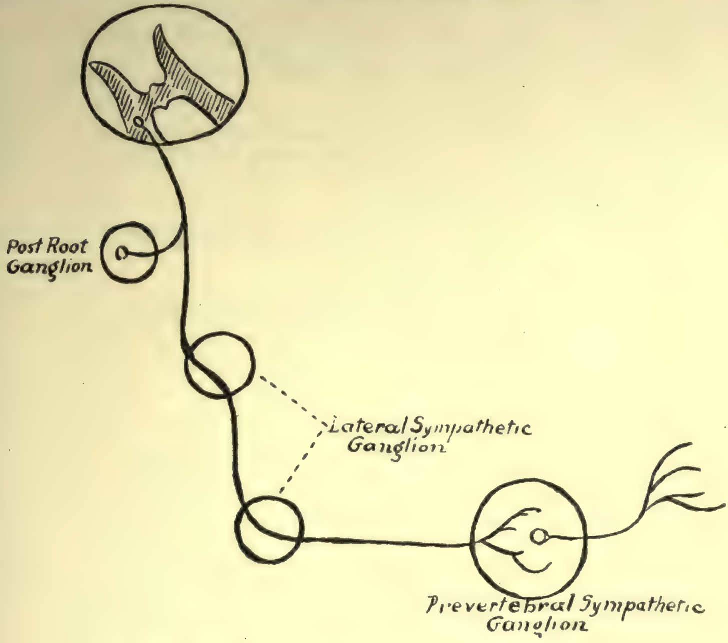
Post Root Ganglion
Lateral Sympathetic Ganglion
Prevertebral Sympathetic Ganglion

Fig. 292.—An Afferent Sympathetic Fiber.

Adrenalin, when injected, produces all the effects seen from stimulating the sympathetic nerves, but does not produce any of the effect characteristic of stimulation of the parasympathetic nerves. Hence it is a test-agent for the presence of sympathetic fibers.

The pilomotor nerves come from the cord, from the fourth

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on account of their more regularly metameric distribution); in the middle the ganglia of the sympathetic chain. These ganglia give off branches of distribution in which join the cutaneous nerve belonging to the same metamere as the branch itself and the ganglion which has given it off. On the other hand, these ganglia receive branches of medullary origin which arise from segments of the spinal cord situated either higher or lower than the corresponding metamere. Spinal origins condensed in the thoracic region, supplementary regions in the medulla oblongata and the sacral spinal cord. Symmetrical arrangement with regard to a plane (xy) cutting across the middle of the thoracic region.

thoracic to the third lumbar nerves, in the cat, and are distributed to the unstriped muscle about the roots of the hairs and cause erection of them. The condition of the skin known as "goose-skin" is due to these nerves.

Sympathetic fibers, according to their distribution, can be divided into cutaneous or somatic, and visceral or splanchnic.

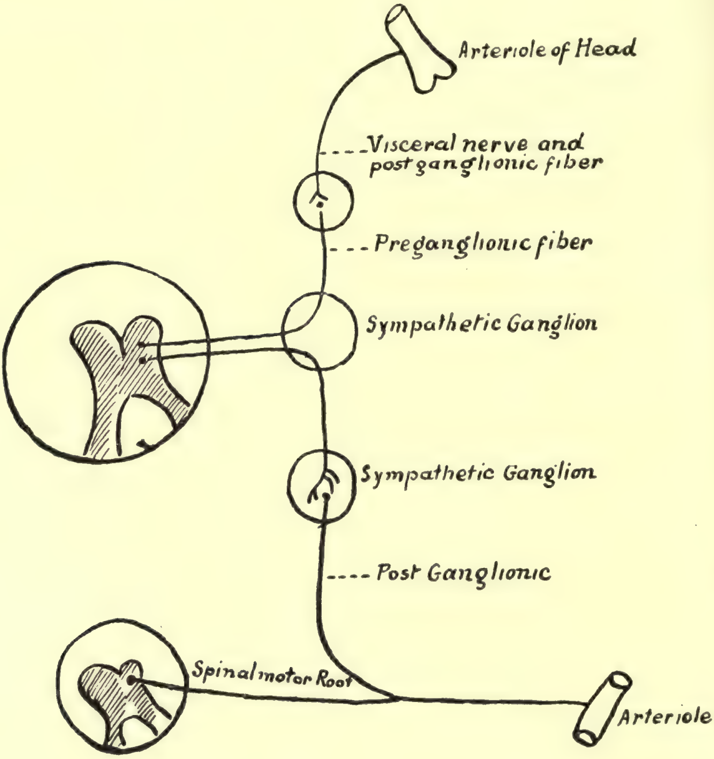

Arteriole of Head
Visceral nerve and postganglionic fiber
Preganglionic fiber
Sympathetic Ganglion
Sympathetic Ganglion
Post Ganglionic
Spinal motor Root
Arteriole

Fig. 293.—Efferent Sympathetic Fiber.

Afferent fibers take their origin in the ganglion of the posterior root. The efferent fibers arise from the intermedio-lateral column of cells, and pass out by the anterior roots.

The efferent fibers of the head and neck come from the upper five dorsal nerves, and run up in the cervical sympathetic to the superior cervical ganglion, where they have their cell station. From this ganglion the following fibers arise:—

1. Vasocontrictors.

2. Pupillo-dilator to the Gasserian ganglion, in the ophthalmic branch and long ciliary nerves to dilator fibers of the iris.

3. Motor to Müller's smooth muscle of the orbit and Tenon's capsule.

4. Secretory to sweat-glands.

If you irritate the cervical portion of the sympathetic, the eyeball is projected by a contraction of the smooth, muscular fibers of the capsule of Tenon; the pupil dilated. The recti muscles push the eyeball inward. The vasomotor nerves, constrictors, and dilators are in the cervical sympathetic, and when it is irritated the blood-vessels of the ear, conjunctiva, iris, tongue, epiglottis, and palate are contracted, whilst we have a dilatation of the vessels of the retina, lips, gums, and nasal mucous membrane.

The cervical sympathetic also acts upon the circulation of the brain and that of the thyroid gland.

Thorax.—The fibers of the thoracic organs arise from the five upper dorsal nerves, go out through the first thoracic ganglion, then go through the annulus of Vieussens to the inferior cervical ganglion, and pass to the heart and lungs, as the cardio-accelerator and the vasoconstrictors of the lungs.

Abdomen.—These fibers come off from the lower six dorsal and upper three lumbar nerves. The great splanchnic nerve is formed by branches from the fifth to the tenth thoracic ganglia, and terminates in the semilunar ganglion of the solar plexus and in the superior mesenteric plexus.

The lesser splanchnic is formed by filaments from the tenth to eleventh thoracic ganglia, and goes to the solar and renal plexus. The splanchnic nerves are the greatest vasoconstrictor nerves in the body, and contain inhibitory fibers of the small intestines. They also contain motor fibers to the intestines.

Pelvis.—The fibers for the pelvis emerge from the cord by the lower dorsal and upper four lumbar nerves, and have their cell-station in the inferior mesenteric ganglia, from which they run in the hypogastric nerves to the pelvic ganglia. They contain vasoconstrictors, inhibit the colon, give motor-power to the bladder, uterus, and vagina.

The mesenteric nerves go to the superior mesenteric ganglion, and then to the hypogastric plexus. The cœliac, the superior mesenteric, and the hypogastric prevertebral ganglia are united amongst themselves by connections parallel to the sympathetic chain. These ganglia form in some sort a second chain anterior to that which follows the lumbar vertebral chain. This prevertebral chain receives elements of reinforcement by two remarkable paths. The first is that of the vagus, which carries bulbar influences. The second is that path formed by the nervi erigentes, which come off from the second and third sacral nerves and, like the bulbar and midbrain nerves, do not enter the sympathetic ganglia, but go to the hypogastric plexus near the bladder, where the fibers have their cell-station. They are vasodilator nerves to the pelvic organs, inhibit the retractor penis, and are motor to the bladder, colon, and rectum.

In the heart and lungs, the vagus is inhibitory and the sympathetic is accelerator. For the gastric and intestinal muscles the pneumogastric mainly augments, whilst the sympathetic chiefly inhibits.

Arm.—These fibers come out by the fourth to tenth dorsal nerves, and send fibers to the stellate ganglion and from there pass into the spinal nerves, and go to the blood-vessels, sweat-glands, and pilomotor muscles of the skin and limb.

Leg.—These fibers take origin from the eleventh dorsal to third lumbar nerves, and come out of the last two lumbar and first two sacral ganglia and go to the leg in the spinal nerves, to supply the blood-vessels and pilomotor muscles and secretory nerves.

Langley regards the nerve-cells of Auerbach and Meissner's plexus of the intestinal tract (the enteric nervous system) as different, both from the sympathetic and parasympathetic system. He does not know if they are connected with the sympathetic or parasympathetic, but doubts it. Magnus has shown that the nerve-cells of Auerbach's plexus are reflex centers for the rhythmic contractions of the intestines. Langley believes that in the intestine there are two sets of nerve-cells, one motor, the other inhibitory, both acting on the muscular tissue, the state of the muscle depending on the balance of the two forces.

Afferent Fibers.—They have their cell-station in the ganglion of the posterior root. They enter the cord largely by the white rami. Normally, stimulation of their peripheral endings does not lead to modifications of consciousness, and is therefore not accompanied by pain. In abnormal conditions painful sensations are produced.

Head has shown that the sensation of pain from visceral diseases is referred to certain points on the surface of the body. Thus, intestinal trouble causes pain in the skin of the back, abdomen, and loins. In stomach troubles, the pain is referred to the ensiform cartilage; in disease of the heart, to the scapular region. Here the pain in the skin is due to the segment of the spinal cord from which the organ concerned receives its sensory fibers, there being a spread of it through the nerve-centers, and thus causing an error in its localization.

Blows on the solar plexus reflexly cause arrest of the heart. The splanchnics also have sensory nerves for the intestine, and in intestinal cramp may give rise to extremely painful sensations. In the colic due to lead-poisoning, we have an affection of the sympathetic ganglia.

Reflex Action of the Sympathetic Ganglia.—Sokownin has found that when in the cat the nervous connections of the inferior mesenteric ganglion are divided, with the exception of the hypogastric nerves, and when the central cut end of one hypogastric is stimulated, contraction of the bladder ensues on the opposite side. According to Langley, this is not a true reflex, but an axon reflex.

CHAPTER XV.

SPECIAL SENSES.

TACTILE SENSE.

THE organs of special sense constitute the peripheral portion of the centripetal part of the nervous system. The nervous system is open to receive the impressions from the external world according to the nature of the different agents which must impress the organs of the special senses.

The various kinds of sense-organs have each a different construction. They are always adapted to receive an impression of a given agent. Thus, the eye is an organ that is particularly adapted to receive impressions from rays of light; the ear receives sound-waves; the skin is responsive to touch, etc.

Man is endowed with *five senses.* That is, he possesses five kinds of organs which are destined to give him notice of the impressions upon his nervous system from five different agents. To these agents man has assigned special names which recall their relations to the organs of sense, and without which they could not be conceived of. These agents, with the corresponding organs of sense, are (1) *contact,* which is perceived through the sense of touch, whose highest development is in the skin; (2) *taste,* a modification of touch is perceived through the *sense* of *taste* embodied in the tongue; (3) odor is recognized through the *sense* of *smell* as located in the nose; (4) sound-waves are made known to the economy through the *sense* of *hearing,* whose peripheral organ is the ear; and (5) light is perceived through *sight* by reason of the response produced in the eye from the excitation of rays of light.

Müller's law of the specific energy of sensory nerves is that irritation of the nerves of special sense always causes sensations of the same kind. An induction current upon the skin will produce unpleasant *tactile sensations.* Upon the eye it provokes *luminous* sensations, upon the ear, *noise* sensations, and upon the tongue there is produced a sensation of *taste.* Yet in each case the stimulus is always the same.

In order that the impressions caused by the external excitants may be able to reach the consciousness of the individual, it becomes necessary that each organ of sense be furnished with centripetal nerves. These are in direct anatomical relation with the central nervous system. By means of these nerves the cortical portion of the cerebrum, endowed with consciousness, perceives the impressions coming from the external world. These are the so-called special, external and objective sensations.

Among the *parts furnished* with nerves of general sensibility are the *mucous membrane* of the *digestive, respiratory,* and *genito-urinary tracts,* and the *skeletal muscles.* In the digestive tract, the mouth, pharynx, and anus are endowed with tactile nerves; the rest of the tract is furnished with nerves of general sensibility. The mucous membrane of the œsophagus gives us the sensation of thirst, the gastric mucous membrane the sensation of hunger and satiety, while the rectal membrane notifies the individual of the need of defecation.

Pulmonary tissue in itself has but very little sensibility; but abnormal irritations cause cough and painful sensation. The pleura, when invaded by disease, produces very painful sensations.

The *genito-urinary* membrane, besides its exquisite tactile sensibility, is also the seat of general sensibility that is doubly modified: in the need of urination and the sexual sense. The kidneys, ureters, testes, Fallopian tubes, and the uterus are endowed only with nerves of general sensibility.

The *skeletal* muscles are furnished with the so-called muscular sense.

Muscular Sense.—According to Dr. Sherrington, of Liverpool, this is a specific sensation obtained from specific sense-organs in muscles, tendons, joints, and all the accessory organs of movement. In the muscles of the skeleton there are three sets of sensory organs: muscle-spindles, tendon-organs, and Pacini corpuscles.

Muscle-spindles, or neuromuscular spindles, are long, narrow bodies, with a thick sheath of connective tissue enclosing fine striped muscular fibers. Sensory, medullated nerve-fibers enter the spindle, dividing into branches, and losing their medulla form endings around and between the muscular fibers. The perception of muscular sense may be grouped into: (1) those of posture; (2) those of passive movement; (3) those of active movement; and (4) those of resistance to movement.

To the organs of muscular sense is largely traceable a local feeling of fatigue.

The nerves of muscle are competent to produce pain; this is proved by the pain of muscular cramp.

A proof of muscular sense is the employment of enough force to overcome resistance. Consciousness is a large factor in this last function, for by it the individual judges the amount of resistance. He then voluntarily regulates the amount of muscular effort.

It is by the sum of all the sensations from the nerves of general sensibility, as well as the sensation produced by muscular movement, that individuals feel that they exist. With these data the individual recognizes the state of different parts of his body, whether in repose or activity.

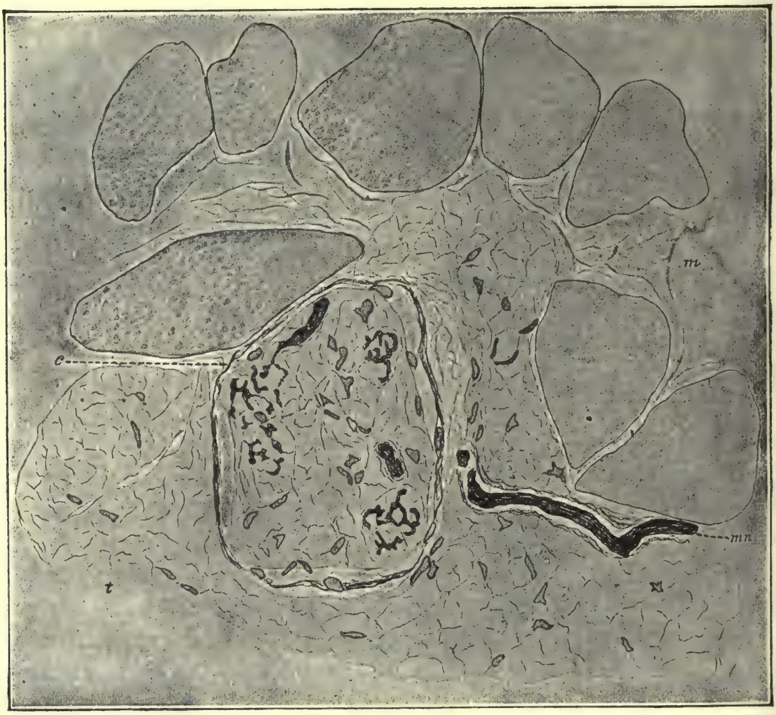


Fig. 294.—Cross-section of Neurotendinous Nerve End-organ of Rabbit from Tissue Stained in Methylene Blue. (Huber and Dewitt.)

m, Muscle fibers. *t*, Tendon. *c*, Capsule of neuro-tendinous end-organ. *mn*, Medullated nerve fiber.

Laws of Sensation.—Special sensations are subject to the following laws:—

1. For every nerve of sense there is a nominal degree or limit of stimulus which gives no sensation whatever. There is also a maximum degree beyond which an increase of the intensity of the stimulus brings on pain or an unpleasant sensation.

2. The minimum limit varies for the separate sensations, or, rather, the single specific agents. Thus, the minimum for excitation of touch is a pressure of 0.002 milligrams; for temperature, $^1/_8$° C.; for sensation of movement, a shortening to the extent of 0.044 millimeters of the internal rectus of the eye; for hearing, the noise made by a ball of pith one milligram in weight falling one millimeter in height upon a glass plate heard at a distance of ninety-one millimeters from the ear; for sight, an intensity of light about three hundred times feebler than that of the full moon.

3. The intensity of the sensation is proportional to the intensity of the stimulus and the degree of irritability of the nerve at the moment of excitation. As the strength of the stimulus increases, so do the sensations. But the sensations increase equally when the strength of the stimulus increases in relative proportions. Thus, small noises will be distinguished in the silence, not in the midst of loud noises; a slight difference will be noticed between small weights, not between heavy ones. A burning candle in the daytime makes little impression.

4. Sensations do not increase in the same proportion as the stimulus. If the stimulus increases in geometrical progression, then the sensation increases in simple arithmetical progression. Rather, it increases as the *logarithm* of the *strength* of the *stimulus.* (This is Fechner's psycho-physical law.)

5. For the single, specific sense apparatuses, whenever a stimulus takes place, whether at the peripheral terminations of a nerve or in its course, or at its central point, the *individual always localizes with his perception the stimulus at the place where the normal stimulus operates.* That is, for sight and hearing he refers it to space; for the nerves of taste, smell, or touch, he refers it to the peripheral regions of his body, even if these be lacking. Thus, in an amputated leg, pain in the stump is referred to the toes. This is the law of eccentric projection of sensation.

Touch.

The organ of touch is represented by the skin and mucous membranes in proximity to the natural orifices of the body.

The skin, or common integument, is composed of the following layers: (1) the *epidermis;* (2) the *corium,* or cutis vera, with its papillæ; and (3) the *subcutaneous tissue* with the adipose tissue.

1. The Epidermis belongs to the tissues which are composed of simple cells united to each other by cement-substance. It in itself consists of several layers.

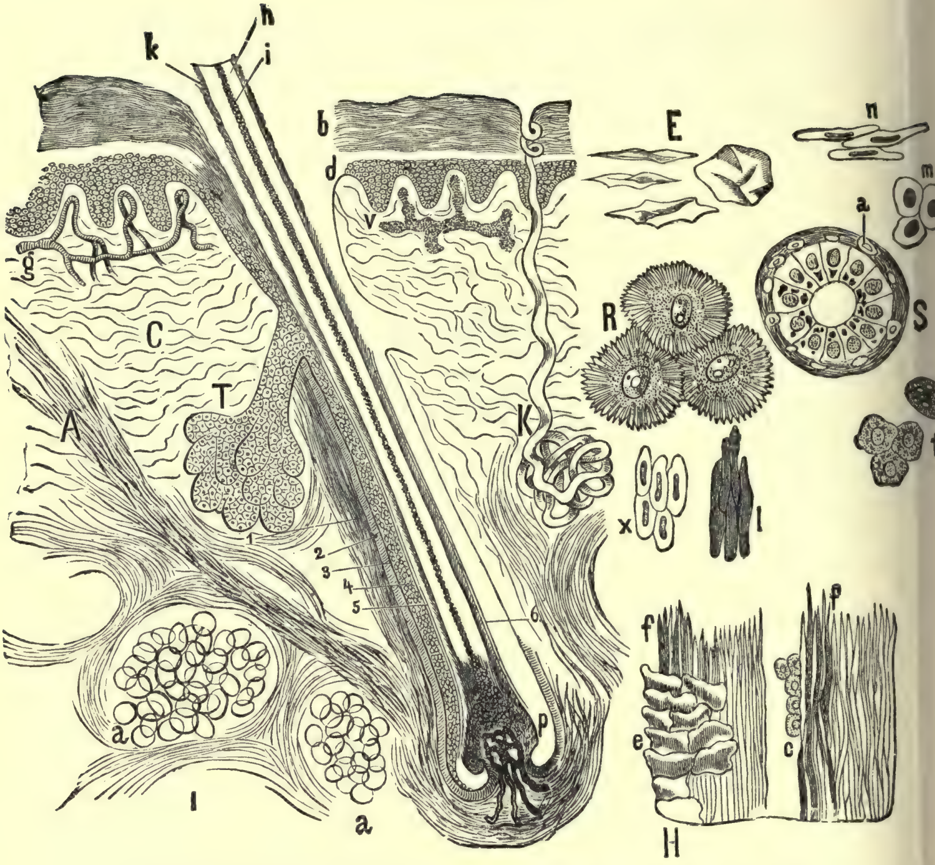


Fig. 295.—Histology of the Skin and the Epidermoidal Structures. (Landois.)

I, Transverse section through the skin, with hair and sebaceous glands (*T*), corium and epidermis are shown in reduced size. 1, External, 2, Internal fibrous layer of the hair-follicle. 3, Cuticula of the hair-follicle. 4, External root-sheath. 5, Henle's layer of the inner root-sheath. 6, Huxley's layer of the inner root-sheath. *p*, Hair-root attached to the vascular hair-papilla. *A*, Arrector pili muscle. *C*, Corium. *a*, Subcutaneous fatty tissue. *b*, Horny layer. *d*, Malpighian mucous layer of the epidermis. *g*, Vessels of the cutaneous papillæ. *v*, Lymphatics of the cutaneous papillæ. *h*, Horny substance. *i*, Medullary canal. *k*, Epidermis of the hair. *K*, Sudoriferous gland. *E*, Epidermal scales from the horny layer, viewed partly from the side, partly from the surface. *R*, Prickle-cells from the Malpighian layer. *n*, Superficial, deep nail-cells. *H*, Hair, more highly magnified. *e*, Epidermis. *c*, Medullary canal with medullary cells. *f*, *f*, Fiber cells of the hair-substance. *x*, Cells of Huxley's layer. 1, Cells of Henle's layer. *S*, Transverse section through a sudoriferous gland of the axillary cavity. *a*, Adjacent unstriated muscular fibers. *t*, Cells of a sebaceous gland, in part with fatty contents.

(*a*) *Stratum Corneum.*—This is the superficial horny layer and consists of several layers of horny scales, without any nuclei. The layers are separated from one another by narrow clefts containing air. They are in a process of desquamation. The variable thickness of the epidermis is chiefly dependent upon the thickness of this outer layer. The stratum corneum is of greater thickness on the palm of the hand and fingers, and sole of the foot.

(*b*) The *stratum lucidum* is clear and transparent and consists of a few layers of clear cells which contain but the remains of nuclei.

(*c*) *Stratum Granulosum.*—Under this is the (*d*) *rete mucosum*, or *rete Malpighii.* This layer consists of strata of nucleated, protoplasmic, epithelial cells. In the colored races these contain pigment. Among the fair races this layer of the skin of the scrotum and anus contains pigment-granules. The deeper cells are more or less polyhedral, while the deepest ones are columnar. These last are placed vertically upon the papillæ and are provided with spherical nuclei. Granular leucocytes or wandering cells are occasionally found between these cells.

The superficial layers of the epidermis are continually being thrown off, while new cells are just as rapidly being formed in the deep layers. Within them there occurs a proliferation of the cells of the rete Malpighii. Many of the cells exhibit the changes of karyokinesis. No pigment is formed within the epidermis itself. But in brunettes and colored races pigment granules of melanin exist within the cells of the lowermost layers of the stratum Malpighii. The pigment-granules owe their presence here to their having been carried thither by leucocytes from the subcutaneous tissue. This explains how a piece of white skin transplanted to a colored person becomes black.

2. The Corium, or *cutis vera,* is a dense network of fibrous connective tissue admixed with elastic fibers. Its entire surface is studded with numerous *papillæ,* the largest of which are upon the volar surface of the hand and foot. The majority of the papillæ contain a looped capillary. In some regions of the surface of the body they contain *touch-corpuscles.* The papillæ are arranged in groups whose disposition varies in the several parts of the body.

The lowermost connective-tissue layers of the corium gradually merge into the *subcutaneous tissue.* Its arrangement is such as to leave spaces which contain, for the most part, cells of fat. The subcutaneous connective tissue, composed of ordinary connective tissue, is soft, and is rich in adipose cells, vessels, nerves, and lymphatics.

Tactile Corpuscles.—The student well knows that in the epithelium of the skin and mucous membranes the nerves of common sensation are arranged, for the most part, in *networks* of fibrillæ. In addition to these there are other special terminal organs of sensory nerves. These are variously known as tactile corpuscles. These are concerned in the perception of some special quality or quantity of sensory impulses. They have their site, not in the surface of the epidermis, but deeper within the tissues. The principal ones among them are the *corpuscles* of *Pacini,* the *end-bulbs* of *Krause,* the *corpuscles* of *Meissner,* and the *corpuscles* of *Merkel.*

The tactile corpuscles of Meissner in the papilla of the cutis vera are oval bodies $^1/_{30}$ of an inch in length and nearly the same width. These are the corpuscles of the palm of the hand and sole of the foot. One or two medullated nerve-fibers are spirally twisted around it, and near the top of the corpuscles the nerves lose their white substance and the axis-cylinders end in flat bodies penetrating the surface of the corpuscle. The corpuscle is composed of flattened cells, which give it a striated appearance. These corpuscles are built up of a great number of tactile discs and of tactile cells. There are about twenty tactile corpuscles to a square millimeter of the skin.

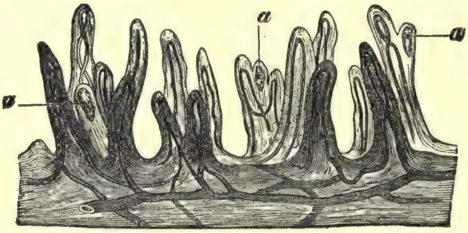


Fig. 296.—Cutaneous Papillæ Deprived of Their Epidermis and the Vessels Injected. (LANDOIS.)

a, a, a, Tactile papillæ, each containing a Meissner corpuscle.

The Pacinian or Vater's corpuscles are attached in greatest number along the digital nerves of the fingers and toes and occasionally on other nerves. These bodies are oval or pyriform, about one-eighth of an inch in length and one-twelfth of an inch in thickness. They have a pearly luster and consist of a series of capsules or concentric layers of fibrous tissue, with here and there a nucleus. The outer capsules are separated more widely than the inner ones and the interspaces are filled with a colorless liquid. Each corpuscle is attached to a nerve by a pedicle of fibrous tissue through which extends a single nerve-fiber, which, penetrating the series of capsules, terminates by sending its neuraxon into the central cavity of the corpuscle, at the top of which it ends in a simple extremity. Each corpuscle is covered with forty or fifty capsulàr layers.

Krause's End-bulbs.—The tactile corpuscles of Krause are elongated, oval bodies, into one end of which a nerve-fiber penetrates. Externally they have a covering of connective tissue, a continuation of the perineurium, and an internal knob of granular matter disposed in concentric layers with a few nuclei. In the center of this knob is found the axis-cylinder which runs through it like a ribbon to the upper pole and then ends in a slight thickening. These bulbs are found in the basement membrane of certain mucous membranes, as in the corneal conjunctiva, in the mucous membrane of the mouth, in the clitoris, and in the glans penis. They are also to be found in the skin.

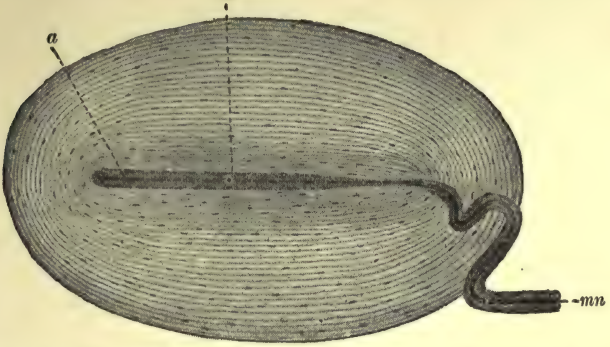


Fig. 297.—Vater Pacinian Corpuscle from the Mesentery of the Cat, Fixed in a Platinum Chlorid-osmic Acid Solution. × 45. (SOBOTTA.)

The figure gives a general view of the corpuscle and not a cross-section. *a*, Axis cylinder in the core. *ik*, Core. *mn*, Medullated nerve-fibers entering the corpuscle.

Corpuscles of Grandry or of Merkel consist of two or more flattened cells, each larger than a simple tactile cell. Each cell is nucleated, and the nerve-fiber, before entering the corpuscle, loses its white sheath, and the axis-cylinder ends as a flat disc lying between the two tactile cel's. These tactile cells are piled one upon the other so as to form a heap of cells. They are found chiefly in the beak and tongue of the duck and in the epiderm of man.

Other Modes of Ending.—In addition to sensory nerves ending by special structures as those just described, there are some which do not possess such elaborate apparatus. In the case of many nerves, the axis-cylinder splits up into fibrils which are arranged in the form of a network. From this somewhat deeply placed network very fine fibrils or fibrillæ are given off to terminate in the tissues to be supplied. The fibrillæ have their terminus in free ends lying between the epithelial cells. In many cases the free ends are seen to be provided with small enlargements. These latter are known as *tactile cells.*

Knowledge Gained.—By the sense of touch one feels the contact of bodies and their temperature, whether these bodies be solid, liquid, or gaseous. This special sense also defines at the same time the *locality* of the impression made by the external agent. The judgment of locality is not, however, free from error. It is really exact for but a few points; that is, wherever the touch is delicate. On the other parts of the skin the individual never exactly divines the point pressed upon; so that he makes mistakes of millimeters, centimeters, and even decimeters.

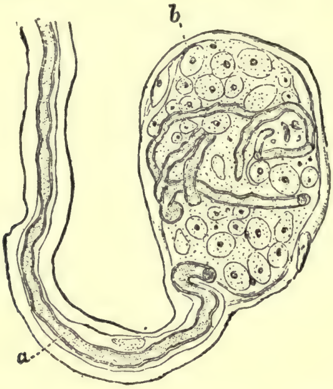


Fig. 298.—Krause's Corpuscle. (HEDON.)

a, Nerve fiber. *b*, Corpuscle.

In sensory *nerve-trunks* there exist different kinds of nerve-fibers; some administer to *painful* impressions and others to *tactile* impressions. Sensations of temperature, sensations of pressure, and of muscular sense belong to the latter group.

There are, then, four sense qualities in skin-sensations: sensations of pain, temperature, pressure, and muscle-sense, and each one has its own nerve-fiber.

SENSE SPOTS.—The surface of the skin is found by experimentation to be composed of very *small sensorial areas.* Between these areas are found little fields which are insensitive and which are relatively much larger than the sensitive areas, or "spots." It has been demonstrated that each "spot" has its own specific function to perform, whether that be touch, cold, warmth, or pain. Each little sensitive area no doubt marks the site of single or groups of sensory corpuscles, end-organs, or bulbs, of the terminations of various nerves. Where the nerves terminate, there are the sense-spots represented upon the skin's surface.

Some one has very aptly likened the skin with its sense-spots to a pond upon whose surface, as well as just below the same, are seen lily leaves floating. The leaves represent the sense-spots. A pebble thrown into the pond may strike one or more leaves, depending upon how close together they are growing. The pebble represents a stimulus, and by its presence temporarily stirs up or throws into a state of excitation the leaves struck as well as some of those adjacent.

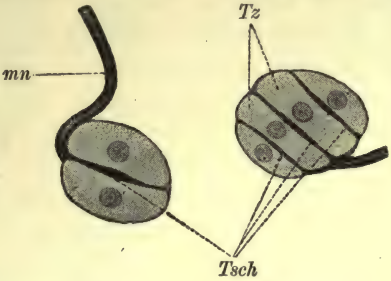


Fig. 299.—Transverse Section of Two Grandry's Corpuscles from the Tongue of a Duck. × 450. (Sobotta.)

One of the corpuscles shows two, and the other, four tactile cells. *mn*, Medullated nerve-fibers, entering the corpuscle. *Tsch*, Tactile discs. *Tz*, Tactile cells.

Upon the skin's surface may be demonstrated "touch-spots," "cold-spots," "warmth-spots," and "pain-spots." These are all mixed up, though those of one kind may be more strongly in evidence in certain areas. As a rule, "pain-spots" are found to be the most numerous; "warmth-spots" are the least likely to be found.

Solids.—These act upon the sense of touch either by *pressure* or by *traction*. Pressure may be from zero to a maximum whose limit is the disorganization of the tissues. Up to a certain minimum, which depends upon the sensibility of the region, the application of pressure excites no sensation. The minimum pressure corresponds to the sensation of simple contact; this by degrees gives way to the sensation of pressure. When the pressure is sufficiently increased there results pain. This in turn disappears when the pressure is increased to disorganization of the tissues.

Pressure varies not only in intensity, but in extent. No matter how the latter may be limited, the pressure always affects at least more than one peripheral nerve-ending.

When tactile sensations are very light and succeed one another rapidly, a large number of nerves is stimulated. The sensation excited is a peculiar one: that of *tickling.*

Traction upon the hair and nails determines pain much more rapidly than does pressure.

Liquids.—Liquids applied at the temperature of the skin exercise a uniform pressure upon all parts of the cutaneous surface excepting those at the level of the surface of the fluid.

If a finger be plunged into a heavy fluid, as metallic mercury, the part submerged bears a pressure which decreases from below upward uniformly. It is only at the surface of the liquid that a marked inequality of pressure exists. It follows a circular line which surrounds the finger at this level and can be plainly felt by the individual. If a lighter fluid, as water, be used, the pressure sensation is but very slight.

Compound Tactile Sensations.—These may be simultaneous or successive. Simultaneous tactile sensation may be either double or multiple. Double sensations, whether of contact, pressure, or traction, are shown only when the stimuli are applied at a certain distance from one another. If the stimuli be near enough, the sensation remains single even though the stimulus has been applied to the skin in two places. The earliest systematic experiments upon this subject were by Weber. He touched the various points of the skin's surface with a pair of carpenter's compasses and then observed the distance of separation necessary to give a distinct impression of two points of contact. The instrument now used for this purpose is the *æsthesiometer.* From the table compiled by Weber it is found that the tip of the tongue is most sensitive, while the thigh and arm are least so. In the case of the tongue, the threshold stimulus, the minimum separation necessary for the impression of double contact is but 1.1 millimeter; 67.6 millimeters are necessary in the case of the thigh and arm. The connection between the mental and physical conditions explains certain *illusions* of tactile sensations. Of these, the best known is the so-called experiment of Aristotle. When a pea or small ball is rolled between the *crossed* index and middle fingers of a blindfolded person there results a sensation of *two balls* being present instead of one.

There are *spots of temperature* which have been worked out by Goldscheider. They are found to be arranged in a linear manner and generally radiate from certain points of the skin, usually the hair-roots. The chain of "cold-spots" does not coincide with those of "warmth-spots." The sensation of cold occurs at once; that of heat develops gradually. As a rule, the cold-spots are more abundant over the entire body surface. The hot-spots may be quite absent. The minimal distance on the forehead for cold-spots is 0.8 millimeters while for warmth-spots it is 5 millimeters.

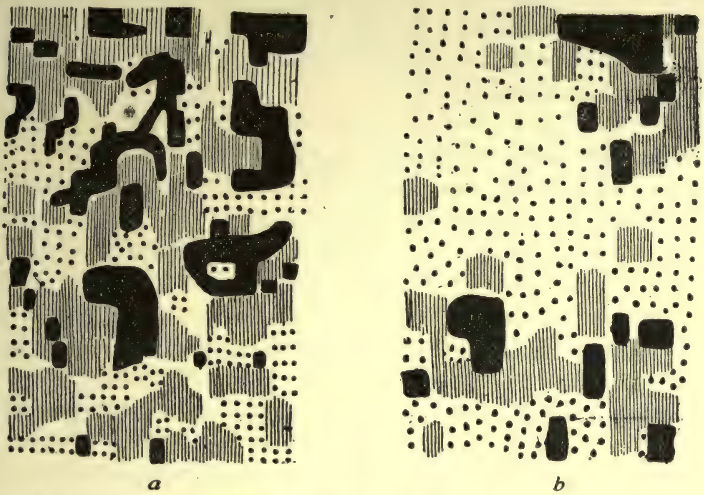


Fig. 300.—Topography of Sensibility to Cold and Heat in the same Region of the Anterior Surface of the Thigh. (GOLDSCHEIDER, HEDON.)

a, Cold spots. *b*, Hot spots. Most sensitive spots in black; moderately sensitive spots are hatched; spot feebly sensitive, in points; spots which are white are not sensitive.

Protection of the Organs of Touch.

The means are the *cutaneous oil* and the *horny appendages*. The cutaneous oil is the product of the sebaceous glands of the skin. They are found in every area of the skin, but are less numerous than the sudorific glands except in the palms of the hands and soles of the feet. They may be large, as in the nose; these usually have fine, downy hairs near their mouths.

The sebaceous glands are situated more superficially than the sweat-glands. They are white granules annexed to the hair-follicle, in which their excretory duct ends. Their size is, in general, inverse to the volume of the corresponding hair-follicle. Where the hairs are large the sebaceous glands seem to be appendages, and when the hairs are small its hair-follicle seems to be an appendage of the sebaceous gland. The glands are aciniform, surrounded by a thin, connective tissue with a basement membrane studded with epithelial cells infiltrated with fat, and the cells are more fatty in the direction of the excreting duct, where is found free fat, due to the destruction of the cells. When the sebaceous secretion stagnates, it forms a fatlike mass which, when expressed, as in the nose, forms the comedo, a wormlike body. The black-heads, as they are called, are dirt in the surface of the gland. When the comedo is pressed out of the duct it has been mistaken as the head of the worm. The sebaceous matter contains, even in healthy individuals, the pimple-mite, or *Demodex folliculorum.*

There are three varieties of sebaceous secretions: (1) the sebaceous secretion proper of the skin, (2) the vernix caseosa of the new-born child, and (3) the smegma of Tyson's glands of the prepuce.

Function.—The sebaceous matter anoints the hairs with oil in their progress of growth from the skin. The greasiness of the surface of the skin caused by this secretion permits the dust readily to adhere, which makes soap necessary to remove its excess. Sebaceous secretion is made up of olein, palmitin, cholesterin, and earthy phosphates.

The organ of touch is also protected by the horny layer of the epidermis, whose cells are being constantly removed by friction and as constantly renewed by proliferation of the cells of the cutis vera.

The *modifications* of the epidermis in man are the *hair* and the nails.

Hair.—The hairs are threadlike appendages to the skin projecting from almost every part of its surface except the palms and soles. They are flexible, elastic, and shining, but vary in degree of development, fineness, color, and form in different races and the sexes as well as in different persons. The color of the hair varies from a light color to a black. The black hairs are found in all parts of the globe and in all latitudes, as in the Esquimaux, negro, Indian, and Malay. All the colored races have black hair, and this is true in some groups of the white race. Red hair is represented in all races. The hair is composed of a projecting part, the stem, terminated by the point, or end. The portion inserted into the skin is the root, which begins in a clublike expansion. The hairs generally project obliquely from the skin. The hairs of the white race are cylindrical; the hair of the negro flattened cylindrical. In structure the hairs consist of an exterior cuticle, a cortex, and an interior medulla. The cuticle consists of a single layer of thin, colorless, quadrilateral scales which overlap like the shingles of a roof. The edges of the scales are directed upward and outward along the shaft. The cortex makes the chief part of the hair, and it is that upon which the color of the hair mainly depends in different individuals. The cortical layer is made up of elongated, fusiform cells containing a lineal nucleus. When the coloring matter disappears in the cortex the hair becomes white. The medulla is frequently absent, especially in the dark-colored hairs. It occupies the axis of the hair. It consists of cuboidal cells with granular contents and an indistinct nucleus. The medullary substance is generally mingled with more or less air, in small bubbles, which penetrates from the ends of the hairs and gives to these when white the characteristic silver luster. The root of the hair is lodged in a flask-shaped receptacle of the skin called the hair-follicle, at the bottom of which is a papilla from which the hair grows. "Goose-flesh" is due to minute muscles contracting and causing the hair-follicles to become erect. At the same time the sebaceous glands are compressed, favoring the exudation of the sebaceous secretion.

Chemically, the hairs are mainly composed of an albuminoid derivative, keratin, in which a notable quantity of sulphur is present: about 5 per cent. In the ashes are found the phosphates, earthy sulphates, oxide of iron, and pigment.

FUNCTION.—The large hairs serve to protect the skin, breaking shocks and preventing a considerable loss of heat. In other places, like the armpits, they prevent friction and attrition of the skin layers. The downlike hairs render the touch more delicate.

Nails.—The nails are hard appendages of the skin, and correspond to the claws of animals. They are flexible, translucent, square-shaped plates continuous with the epiderm and resting on a depressed surface of the dermis called the matrix, or bed.

The exposed part of the nail is the body and its anterior end is its free border. The root of the nail is lodged in a deep groove of the matrix and the lateral borders are received into shallow grooves. The half-moon, or lunule, of the nail is due to a less degree of vascularity of the matrix at the root, defined by a semicircular line. The horny layer corresponds to the cuticle of the epiderm, and is composed of flattened, nucleated cells. The soft layer of the nails, the stratum mucosum, corresponds to that layer of the epiderm. The nails grow in length by new cells at the root, in thickness by additions beneath the nail.

The nails serve to protect the skin at the tips of the phalanges, and, at the same time, perfect the touch of the fleshy parts of the fingers. The average growth of the nails is about one-eighth of an inch per month.

CHAPTER XVI.

SPECIAL SENSES (Continued.)

THE SENSE OF TASTE.

TASTE is an organ of special sense, by which as a medium the individual perceives savory impressions. Its principal uses to the economy are two: First, it acts as a guide to the individual in his choice of food, at the same time rendering its mastication a matter of some pleasure. Secondly, it excites the salivary glands *reflexly,* so that they pour out their juices into the mouth.

The organ of taste is seated in the *oral cavity* and in the mucous membrane of the *tongue.* Its limits are not well defined. The difficulty in their determination depends upon the double fact that these organs of taste are endowed with a very delicate sensibility of a tactile nature, and that the gustatory sensibility and the organ of smell are in very close proximity to one another. For these reasons one may very easily believe that certain regions of his mouth are gustatory, when in reality the substances which have touched them have only produced tactile or olfactory impressions.

Still it has been shown that the principal regions of the oral mucous membrane designed to perceive taste-impressions are at the *base* and *edges* of the *tongue.* In a secondary degree, also, gustatory impressions are perceived in the anterior surface and edge of the soft palate, and the anterior portion of the tongue. All other portions of the mouth are incapable of taste-impressions.

The Tongue.—The principal organ of the sense of taste is undoubtedly the tongue. Its anatomical structure as a muscular organ has already been described when discussing deglutition and the part it played in the rôle of that important function. At this time it remains but to review such portions as have a direct bearing upon its rôle as a gustatory member.

There are three kinds of papillæ in the mucous membrane of the tongue: the *circumvallate, fungiform,* and *filiform.* They extend from the tip of the tongue to the foramen cæcum. The papillæ consist of elevations, visible to the naked eye and covered with stratified, squamous epithelium. The central body of each papilla contains connective tissue, blood- and lymph-vessels, and nerves.

The circumvallate papillæ, the largest of the varieties and about a dozen in number, form a V-like row, defining the papillary layer at the posterior third of the tongue. They have the form of an inverted cone surrounded by a ringlike wall-elevation.

The fungiform are next in size, and more numerous than the circumvallate. They are small, red eminences scattered over the surface of the tongue, but are especially numerous at and near the tip. They are rounded at the free extremity and narrower at the point of attachment to the tongue.

The filiform papillæ, smaller and more numerous than the others, are crowded in the spaces between the others, but are arranged in rows diverging from the median line of the tongue.

Nerves.—The tongue receives three nerves: one of *motion*, the *hypoglossal*, which animates the muscles; and two other *sensory* branches—the *lingual* branch of the *glosso-pharyngeal* and the *lingual* branch of the *trigeminus*. The former of the latter two branches spreads in the mucous membrane at the *base* and *edges* of the tongue; the latter is distributed to the mucous membrane of the anterior two-thirds of the tongue. The branches of the glosso-pharyngeal are especially concerned in sensations of *bitterness*, while the branches of the trigeminus are affected principally by *sweet* and *acid tastes*.

Section of the hypoglossal upon both sides causes paralysis of the tongue without injuring its tactile or gustatory sensibilities. Section of the lingual branch of the trigeminus causes only loss of fine tactile sensibility and gustatory sensibility of the anterior two-thirds of the tongue.

Section of the glosso-pharyngeal causes loss of tactile and gustatory sensibility in the mucous membrane at the base of the tongue. Such an animal can swallow bitter and nauseous substances, like colocynth, with impunity.

The gustatory action of the lingual branch of the trigeminus comes from the chorda tympani. The latter is a small nerve which begins in the facial and traverses the middle ear to join the lingual branch at the level of the pterygoid muscles.

The chorda tympani nerve passes from the tongue to the nerve-centers through the lingual nerve, the facial, and finally through the intermediate nerve of Wrisberg.

Taste-organs.—The terminal branches of the glosso-pharyngeal nerve end in the *taste-bulbs*. The taste-bulbs are oval bodies imbedded in the epithelial layer. Each taste-bulb is formed of two kinds of elongated epithelial cells, and their whole outline is barrel-shaped.

The *taste-cells* are narrow and slightly thickened in the middle, where the nucleus is situated. The taste-bulbs occur chiefly on the sides of the circumvallate papilla, although a small number of them are on the fungiform and the soft palate. The ends of the taste-bulbs near the surface have a minute, funnel-like opening called the *taste-pore.* The number of *taste-bodies* is very great. If the glosso-pharyngeal nerve is cut, the taste-bodies degenerate.

The proper stimuli for the end-bulbs of the gustatory nerves are the *savory* substances. These must be dissolved in the liquids of the mouth before they can penetrate the outer cells of the mucous membrane to come into contact with the nerve-filaments in the imbedded bulbs. The most suitable temperature for the thorough testing of liquids is 100° F.

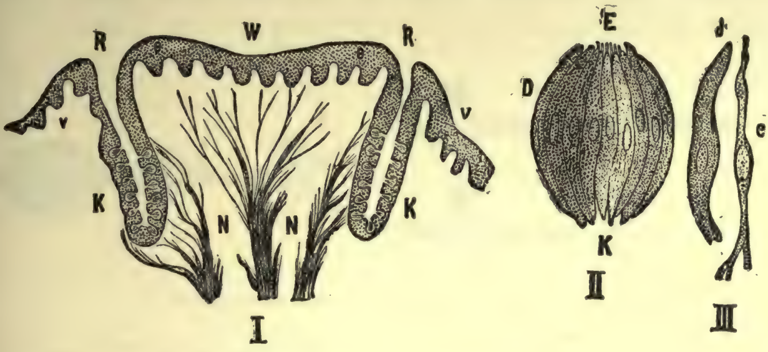


Fig. 301.—Structure of the Taste-organs. (Landois.)

I. Transverse section of a circumvallate papilla. *W*, the papilla. *v*, *v*, The wall in sections. *R*, *R*, The circular slit, or fossa. *K*, *K*, The taste-bulbs in position. *N*, *N*, The nerves.

II. Isolated taste-bulbs. *D*, Supporting, or protective, cells. *K*, Lower end. *E*, Free end, open with the projecting apices of the taste-cells.

III. Isolated protective cell (*d*) with a taste-cell (*e*).

The *intensity* of the gustatory impression depends upon various factors: the nature of the substance, the duration of the impression, sensibility of the region touched, and the stimulating action of the substance upon the mucous membrane. The *flavor* of a substance does not depend upon its chemical properties, for both quinine and sulphate of magnesia are bitter; sugar, chloroform, and glycerin are sweet.

Improper stimuli give gustatory impressions. Thus, the galvanic current applied to the tongue gives an acid taste at the positive pole and a weaker, alkaline taste at the negative pole.

Varieties of Substances.—Of the gustatory substances there are *four:* (1) *sweet,* (2) *bitter,* (3) *acid,* and (4) *saline.* In addition to these fundamental substances there are *compound* gustatory impressions, or a confusion of gustatory sensations with those which are tactile or olfactory. Thus, there is known the piquant taste of cheese, the caustic taste of mustard, and the aromatic taste of strawberries.

The *acid* and *sweet* tastes are best perceived at the *tip* and *edges* of the tongue; the *salty* and *bitter* tastes are comprehended at the *base.* This leads to the result that some substances have a different taste, dependent upon whether they touch the tip or the base of the tongue. Thus, acetate of potassium at the tip of the tongue is acid, and at the base it is bitter.

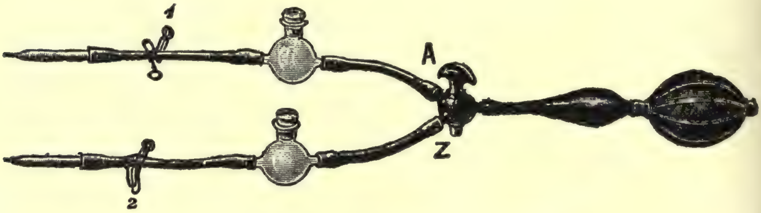


Fig. 302.—Sternberg's Gustometer.

The four primitive tastes are not all perceived at the exact time of their impression upon the tongue. The salty is first perceived, then the sweet, next the acid, and last the bitter.

Tactile sensations by astringents (tannic acid) or thermal sensations (mustard) are usually confounded with taste proper. The taste of vanilla is but an olfactory impression.

Drugs.—By the action of drugs one is able to abolish certain tastes more readily than others. Cocaine upon the tongue abolishes tactile sensations and the taste for bitter things, but does not interfere with voluntary movement.

The leaves of *Gymnema sylvestre,* when chewed, destroy the sense of taste for bitters and sweets, while that for salts and acids remains.

The Taste-center, to which the gustatory nerves send their impressions, lies in the *uncinate gyrus.*

Sternberg's Gustometer.—This instrument consists of a Richardson double-bellows rubber bulb, which is attached to a two-way stopcock. The two-way stopcock is connected by rubber tubes with two glass bulbs fitted with an entrance and an exit tube. Both glass bulbs contain small pieces of sponge, to increase the surface for evaporation of the volatile fluids. In one glass bulb is placed chloroform as a sweet substance to be tasted; in the other glass bulb, ether, to represent a bitter-tasting substance. To the exit tubes of each glass bulb are attached, by rubber tubes, two tubes of glass drawn to a fine point. A spring clip is placed on each rubber connecting-tube. When the apparatus is to be used, the Richardson rubber bulb is compressed and air is driven through one or the other glass bulb. By this means we can, at our pleasure, test for bitter or sweet substances. Even acetic acid can be placed in one of the bulbs, to test the taste for acids.

The pointed glass tubes must be brought near the point on the tongue to be tested, but they must not touch it.

Sternberg has also constructed a quantitative gustometer, on the same principle as the olfactometer of Zwaardemaker.

CHAPTER XVII.

SPECIAL SENSES (Continued.)

THE SENSE OF SMELL.

The seat of the sense of smell resides in the cavities of the nose. Kant has very aptly spoken of smell as "taste at a distance."

The organ of smell resembles those of sight and hearing in that it consists of a special nerve which ends in a specialized epithelium. In this case the special nerve is the *olfactory;* the specialized epithelium is the mucous membrane of the upper portion of the nasal cavity. It is in this portion the mucous membrane that the filaments of the olfactory nerve are distributed. For that reason it has been termed the *regio olfactoria,* and comprises the upper portion of the septum, the upper turbinated, and part of the middle turbinated regions. All other portions of the nasal-cavity covering is known as the *regio respiratoria,* or simply the Schneiderian membrane. During ordinary respiration the currents of air in their passage in and out

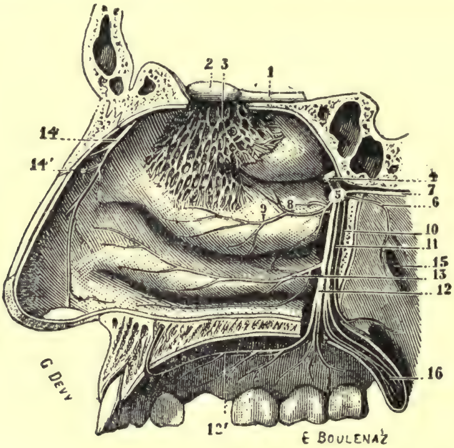


Fig. 303.—Innervation of the External Wall of the Nasal Fossa. (TESTUT.)

1, Olfactory tract. 2, Olfactory bulb. 3, Branches of olfactory nerve. 5, Ganglion of Meckel. 6, Pharyngeal nerve. 7, Vidian nerve. 8, 9, Sphenopalatine. 10, 11, 12, 12′, Palatine nerves with, 13, nasal branch. 14, 14′, Termination of ethmoidal nerve. 15, Opening of Eustachian tube. 16, Vault of palate.

are, for the most part, confined to this latter region. The mucous membrane which covers this portion of the nasal cavity is, in structure and appearance, very similar to that of the trachea. It is composed of layers of ciliated epithelium which rest upon a basement membrane rich in blood-vessels and lymphatics. Among the ciliated cells are found numerous goblet and mucous cells, whose secretions keep the surface of the mucous membrane soft and moist. In it are numerous filaments of the trigeminus, which endow it with tactile sensibility. There are *no* filaments of the olfactory nerve in this region.

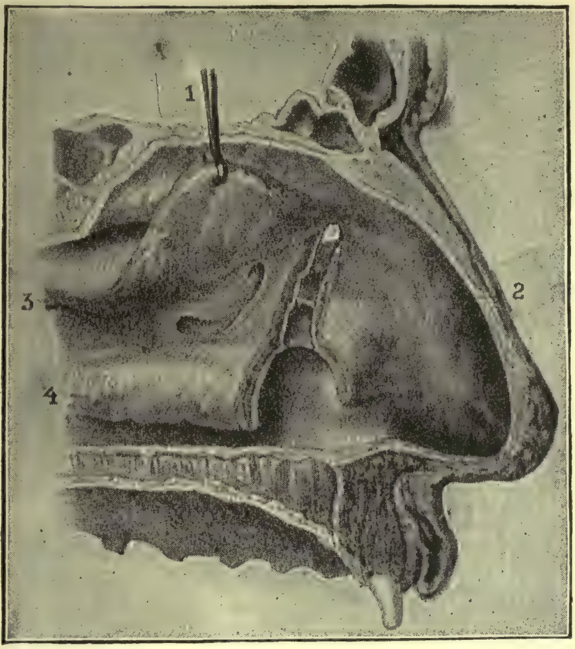


Fig. 304. (Bishop.)

1, Middle turbinated body turned aside and held by a hook. 2, Nasal duct and valves. 3, Canal leading to the maxillary and frontal sinuses. 4, Inferior turbinated body showing the location of the mouth of the nasal duct in the *cul-de-sac*.

The *olfactory mucous membrane* is thicker than that of the respiratory portion. To the naked eye it presents a yellow or brown-yellow color because of the pigment contained within it. By reason of its color it is very readily distinguished from that of the Schneiderian membrane. Its surface is covered by a single layer of *cylindrical epithelium* whose cells are often branched at their lower ends.

The olfactory region contains the *olfactory cells.* These possess a body of spindle shape with a large nucleus containing nucleoli. In the deeper part the olfactory cells pass into and become continuous with fine fibers. These last pass into the olfactory nerve.

The *olfactory,* the nerve of smell, issues by two roots, each from the corresponding hemisphere. The fibers are composed of medullated and nonmedullated fibers.

These latter fibers proceed from the olfactory bulb.

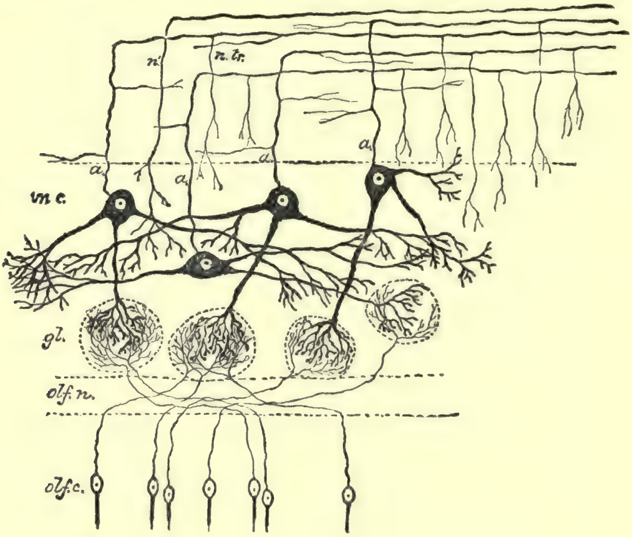


Fig. 305.—Diagram of the Connections of Cells and Fibers in the Olfactory Bulb. (SCHÄFER, in Quain's Anatomy.)

olf.c, Cells of the olfactory mucous membrane. *olf.n,* Deepest layer of the bulb, composed of the olfactory nerve-fibers which are prolonged from the olfactory cells. *gl,* Olfactory glomeruli, containing arborization of the olfactory nerve-fibers and of the dendrons of the mitral cells. *mc,* mitral cells. *a,* Thin axis-cylinder process passing toward the nerve-fiber layer, *n.tr,* of the bulb to become continuous with fibers of the olfactory tract; these axis-cylinder processes are seen to give off collaterals, some of which pass again into the deeper layers of the bulb. *n',* A nerve-fiber from the olfactory tract ramifying in the gray matter of the bulb.

The olfactory bulb is a part of the cerebral cortex and is an oval or club-shaped mass of gray matter which rests on the cribriform plate of the ethmoid bone, through the foramen of which it is connected with the olfactory nerves. The olfactory nerves are twenty in number and are the central coursing of the neuraxons of the rod-shaped olfactory nerve-cells in the olfactory region of the nose. They pass through the openings in the cribriform plate and terminate in arborizations about the dendrons of the mitral cells of the olfactory glomeruli. These bipolar cells greatly resemble the cells of a ganglion of a posterior root of the spinal cord, one neuraxon going to the olfactory mucous membrane and the central neuraxon going to the olfactory bulb.

The olfactory bulb from without inward consists of four layers:—

1. The nerve-fibers.
2. Stratum glomerulosum.
3. Stratum gelatinosum.
4. Layer of central nerve-fibers.

In the first layer each fibril is a central neuraxon of a rod-shaped nerve-cell from the olfactory mucous membrane. The fibers of the olfactory nerves pass into the glomeruli lying beneath. Within the glomerulus the endings of the olfactory fibrils come in contact with an olfactory end-brush of an apical dendron of a mitral cell.

In the stratum glomerulosum each glomerulus consists of the terminal arborizations of an olfactory nerve-fiber, together with the olfactory end-brushes from the apical dendrons of the mitral cells.

The stratum gelatinosum in its inner part contains two chief forms of cells: the deep and superficial layers of mitral cells which correspond to the pyramidal cells of the cerebral cortex.

The fourth layer in its outer part has a large number of very small granular cells between which pass the descending neuraxons of the mitral cells. The nerve-fibers of the olfactory bulbs collect at their posterior extremities into two bundles: the olfactory tracts. The outer root-fibers of the olfactory tract come into relation with the gyrus hippocampus, the uncus, and cornu ammonis. The inner root-fibers pass into the gyrus fornicatus.

Olfactory Sensations.—The student, in order to obtain clear-cut ideas as to the mechanism of the special sense of smell, should bear in mind the principle of the arrangement of the olfactory nerve-terminations. It is recalled that within the mucous membrane lie the olfactory cells. From the peripheral end of each cell project seven or eight ciliumlike processes. These not only project to the surface of the mucous membrane, but even to the *surface of the serous fluid* moistening the membrane. Thus, the terminal filaments are placed in an *exposed position* so that they may very readily respond to any irritant.

The *proper stimulus* for olfactory-nerve filaments are *odorous substances* which reach the regio olfactoria through the air and must be in a volatile state. Hence, olfactory sensations are produced by volatile, odorous particles coming into *direct contact* with the exposed nerve-filaments during the act of inspiration. As the regio olfactoria is in the highest position of the nasal cavity, it becomes necessary for the individual to cause the inspired air forcibly to reach this area. This is accomplished by an act ordinarily known as "sniffing."

During ordinary respiration the inspired and expired air courses along close to the septum and below the inferior turbinated bone. Should the respired air be heavily charged with odorous particles, of course some will find their way into the regio olfactoria, as the air in this compartment is gradually changed. There will then result a sensation of smell, but it will be faint and not so sharply defined as when the person sniffs. By the latter process the air is changed more quickly and a greater number of volatile particles irritate the exposed nerve-endings, with the result of a sharply defined sensation. The sensation seems to occur at the *first moment* of contact of the odorous particles with the mucous membrane. The olfactory nerve tires very quickly when an odor acts for a certain time; the effect becomes weaker and weaker little by little, until the odor is finally unperceived.

Should the free movement of the air be prevented—as, for example, when nasal catarrh brings on a tumefaction of the mucous membrane of the inferior turbinate,—the odorous impression cannot take place.

In case many different odors act simultaneously upon one nasal cavity, the individual receives a mixed sensation. Should but two odors act, the one is perceived on the right half of the mucous membrane of the cavity, the other upon the left half. This is not a true mixture, for the person perceives slightly the one odor and slightly the other. One part of vanillin to 10,000,000 can be recognized by the sense of smell.

SECONDARY SENSATION.—The olfactory impression having been made, the secondary after-sensation often remains for a long time. This is particularly the case with strong, disagreeable odors. This phenomenon is explained on the supposition that the odorous particles remain in the cavity of the nose, even in the air. It is not believed that the manifestation is due to persistence of excitation of the olfactory nerve-fibers after the stimulus has been removed.

There are *subjective olfactory sensations* which are true hallucinations. They are often met with in demented, in hysterical, or in pregnant women. These sensations owe their existence to some material alteration of the nervous apparatus.

From impressions truly olfactory it becomes necessary to distinguish the gustatory as well as tactile or irritative sensations upon the nasal mucous membrane. The irritation and even pain produced by the vapors of ammonia often lead it to be improperly classed as "having a bad odor." Experimentally, a dog with both olfactories divided always starts from the odor of ammonia or of acetic acid. This is due to painful stimulation of his Schneiderian membrane, which gets its sensory nerve-filaments from the second branch of the trigeminus.

Uses.—The organ of smell represents an advance sentinel for the functions of respiration and alimentation. Among the lower animals it serves for the recognition of sex.

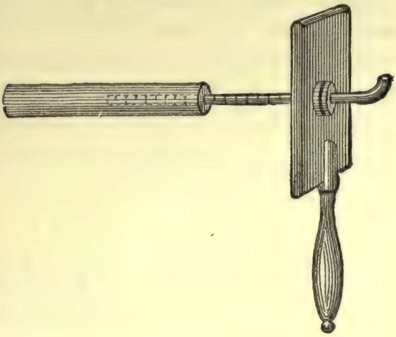


Fig. 306.—Zwaardemaker's Olfactometer. (TIGERSTEDT.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Hyperosmia and Anosmia.—Hyperosmia, or increased sensitiveness of smell, is a common condition. It is very apt to be found among the hysterical and in many other nervous disorders. Strychnine is one of the drugs which is capable of producing this condition when it is applied locally in solution.

Anosmia is a term used to designate a condition which is the reverse of the beforementioned. It may be complete, when it is usually congenital. In such a case the olfactory nerves are absent. It is more usual, however, to find the condition *partial.* Its causes may be stenosis of the nasal cavities, disease of the olfactory mucous membrane, or nervous diseases. Strychnine often relieves the condition.

The local application of a dilute solution of strychnia heightens the sense of smell (hyperosmia). Smoking, the local application of morphia and cocain produce partial loss of the sense of smell (anosmia).

Certain odors can antagonize another odor when perceived by separate nostrils, so that no odor is perceived, as acetic acid and ammonia. There is also a relationship between smell and the chemico-physical properties of odors; it follows the periodic law of Mendelejeff.

The Center of Smell lies in the tip of the uncinate gyrus upon the inner surface of the cerebral hemisphere.

Zwaardemaker's Olfactometer.—Rubber tubing, two inches in length, is fitted inside a glass tube, which prevents any particles of odor leaving its surface. Another glass tube is closely fitted inside the rubber tube. When the inner glass is drawn out .7 centimeters, then a normal person can perceive the odor of rubber, when air is drawn through the inner graduated glass tube. Hence the inner glass rod was graduated in degrees of .7 centimeters. If a man can only perceive rubber at 1.4 centimeters, he has only half normal olfaction; but in certain cases of considerable want of olfaction the odor of rubber is not strong enough to be perceived. Here he used a tube of "gutta percha ammoniacum," which is twenty-four times more powerful as a stimulus than india rubber. It was found, in many cases of anosmia, that certain odors might be smelt to a normal extent, whilst others barely stimulated the olfactory organs.

CHAPTER XVIII.

SPECIAL SENSES (Continued.)

THE SENSE OF HEARING.

By means of the special sense of hearing the individual gains knowledge of a kind differing from the just-mentioned senses. It does not tell him what is going on in the outer world by actual contact, as in touch or taste; nor yet by particles of matter impinging upon the exposed end of nerve-filaments, as in the sense of smell. In the special sense of hearing the impressions conveyed to the central nervous system are produced by wavelike vibrations in the surrounding air. For the reception of these vibrations, so that they may be properly interpreted and the corresponding impressions conveyed to the brain, it becomes necessary to have a special sense-organ: the *ear*.

The Ear.

The organ of hearing in its greatest simplicity may be represented by a small membrane stretched like a drumhead over the bottom of a funnel-shaped tube. The tube opens upon the surface of the body so that it is in direct communication with the enveloping atmosphere. The membrane is so disposed that it is readily thrown into vibrations when the external air becomes undulatory as the result of vibrations of some body. Its vibrations are communicated to an inner vesicle that is filled with a liquid. The liquid is likewise thrown into waves whose undulations stimulate the ramifications of the auditory nerve which are spread out upon the walls of the vibrating vesicle.

Anatomy.—The apparatus for hearing is composed of three parts: *external ear, middle ear,* and *internal ear.*

External Ear.—The external ear is composed of the *auricle* and *external auditory meatus.*

The *auricle* has the form of an irregularly shaped shell. It is composed of yellow, elastic cartilage which is covered over with skin. From its shape one might readily believe that the function of the auricle is to collect and reflect sound-waves into the auricle: that is, to behave in the capacity of an ear-trumpet. But it is found that hearing is perfectly normal in those persons from whom the external ear has been removed by accident or otherwise.

The *external auditory meatus* and *canal* extend from the concha of the auricle to the tympanum. The canal is composed partly of cartilage and partly of bone; the bony portion belongs to the temporal bone. The canal is lined by skin, which contains modified sebaceous and sudoriferous glands. By the glands is secreted the *cerumen,* or earwax.

The internal end of the auditory canal is bounded by an ellipsoid structure which is composed of three layers of tissue: the *tympanic membrane.*

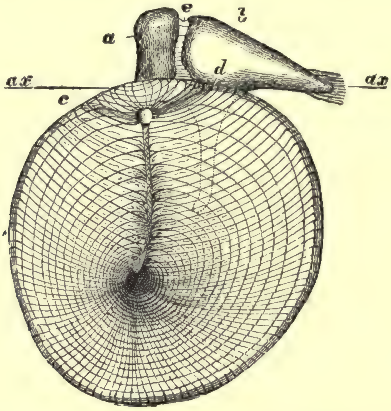


Fig. 307.—Diagram of the External Surface of the Left Tympanic Membrane. (Hensen.)

a, Head of malleus. *b*, Incus. *e*, Joint between malleus and incus. Between *c* and *d* is the flaccid portion of the membrane. *ax*, Axis of rotation of ossicles. The umbo is the deeply shaded part.

Function of the External Ear.—Sound-vibrations strike the external ear, some of which go directly into the external auditory meatus. The irregularity of the surface of the pinna permits us to judge more correctly of the direction and the intensity of sound. If these irregularities are filled up with wax, while the meatus is left open, the intensity of sound is diminished, and it is more difficult to judge of the direction. In the external meatus the waves of sound undergo a series of reflections, which conduct them to the membrana tympani. By reason of the obliquity and curves of the membrana tympani, the sound-waves strike it in a nearly perpendicular direction. The external ear has for its function the collection and transmission of sounds to the membrana tympani. The horse is constantly moving his ears to determine the direction of sounds, but in man this function is greatly subordinated. The twisting of the mouth of the meatus, and the hairs and wax in the external meatus, also keep out dust and insects.

Auditory Field.—Like the visual field, we have an auditory field. It is all the points in space from which sound-waves can be collected by the auricle and transmitted by the auditory canal. Its extent and form depend upon the conformation of the auricle.

MIDDLE EAR, OR TYMPANUM.—The tympanum is a space situated within the substance of the petrous portion of the temporal bone. It is composed of *two bony* and *four soft parts.*

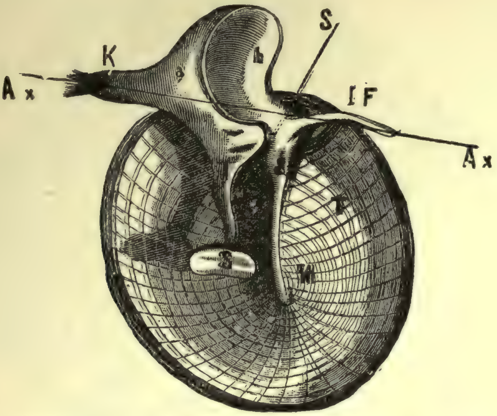


Fig. 308.—Tympanic Membrane and Auditory Ossicles, seen from the Tympanic Cavity. (LANDOIS.)

M, Manubrium, or handle of the malleus. *T*, Insertion of the tensor tympani. *h*, Head. *lF*, Long process of the malleus, or incus-tooth. The short (*K*) and the long (*l*) process. *S*, Plate of the stapes. *Ax* is the common axis of rotation of auditory ossicles. 8, The pinion-wheel arrangement between the malleus and incus.

The *two bony parts* comprise the walls of the cavity, with the *mastoid cells* and Eustachian tube; also the *ossicles* or bones of the ear.

The *soft structures* are: (1) the ligaments and muscles of the little ossicles, (2) the mucous membrane of the tympanic cavity, (3) the lining of the Eustachian tube, and (4) the membrana tympani and membrane of the round window.

In *otitis media* pus may cause a disintegration of the mastoid cells, from which it frequently extends to the membranes of the brain.

The *cavity* of the tympanum forms a dilatation added to the auditory canal. It has an internal wall, an external wall, and the Eustachian tube. The mastoid cells communicate by a large orifice with the upper, back part of the tympanum. They are lined throughout with a delicate mucous membrane.

The *external wall* is occupied in its greatest extent by an opening which is nearly circular and closed by the membrana tympani. The latter is semitransparent, concave externally and convex internally. To its inner surface is attached the *malleus*, one of the three ear ossicles.

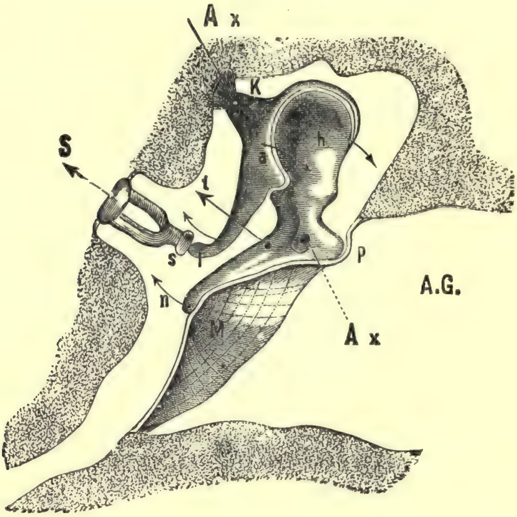


Fig. 309.—Left Tympanum and Auditory Ossicles. (LANDOIS.)

A.G., External meatus. *M*, Membrana tympani, which is attached to the handle of the malleus (*n*) and near its short process (*p*). *h*, Head of the malleus. *a*, Incus. *K*, Its short process, with its ligament. *l*, Long process. *S*, Stapes.

The *internal wall* is convex and has in its central portion a tubercle known as the *promontory.* Its base corresponds to the origin of the *cochlea.* The most prominent of the grooves upon its surface marks the position of the *nerve of Jacobson.*

Above the promonotory is found the *oval window.* Its shape is really reniform; it leads to the vestibule.

The *round window* is situated just beneath the oval window. It is closed by a membrane.

The *ossicles,* which form an articulated chain, reach from the membrana tympani to the oval window. In number they are three: the *malleus,* or mallet; the *incus,* or anvil; and the *stapes,* or stirrup. The three ossicles form a chain suspended across the cavity of the tympanum. The handle of the malleus is inserted into the tympanic membrane; the base of the stirrup is applied to the oval window. Between these two ossicles is suspended the incus. The ossicles have joints which are lined with synovial membrane; there are present suitable ligaments.

The *mucous membrane* of the tympanum is very thin, and either white or rose-colored. It envelops the chain of ossicles.

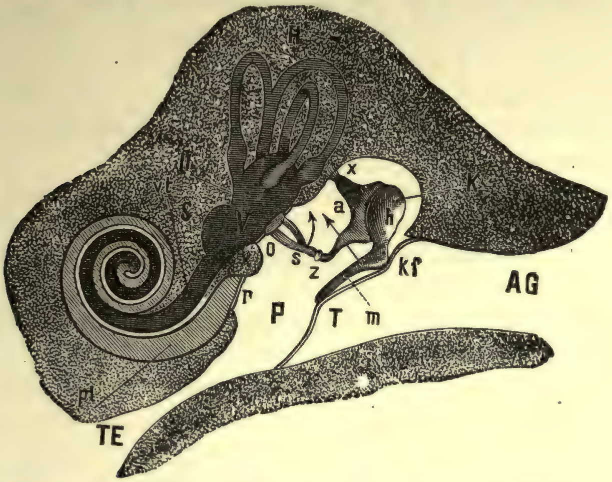


Fig. 310.—Scheme of the Organ of Hearing. (Landois.)

AG, External auditory meatus. *T,* Tympanic membrane. *K,* Malleus with its head (*h*), short process (*kf*), and handle (*m*). *a,* Incus, with its short process (*x*) and long process; the latter is united to the stapes (*s*). *P,* Middle ear. *o,* Oval window. *r,* Round window. *x,* Beginning of the lamina spiralis of the cochlea. *pt,* Its scala tympani. *vt,* Its scala vestibuli. *V,* Vestibule. *S,* Saccule. U, Tubercle. *H,* Semicircular canals. *TE,* Eustachian tube. The long arrow indicates the line of traction of the tensor tympani; the short curved one that of the stapedius.

The *Eustachian tube* is composed of a bony and a cartilaginous part. The canal opens at the anterior upper part of the tympanum; its pharyngeal orifice is situated ten millimeters behind the posterior extremity of the nasal fossa.

The Bony Labyrinth, or Internal Ear.—This structure is imbedded within the substance of the petrous portion of the temporal bone. Its long axis lies in a position parallel with that of the bone. The labyrinth is composed of three portions: *vestibule, semicircular canals,* and *cochlea.*

The *vestibule* is an oval, irregular cavity, lying between the tympanum and the bottom of the internal auditory meatus. The semicircular canals open from it posteriorly and the cochlea opens from it anteriorly. Through its outer wall it communicates with the tympanum by the oval window. The *fovea hemispherica* and *fovea hemielliptica* are two depressions upon the inner and superior walls of the vestibule, respectively. They are pierced by numerous foramina; through the former pass the filaments of the *cochlear* branch of the auditory nerve; through the latter foramina pass the branches of the *vestibular* branch. Through the latter also pass small veins which communicate with the inferior petrosal sinus.

The *semicircular canals* are three in number. They are located above the inner and back part of the tympanum. From their location they are named *superior, posterior,* and *external.* The canals lie in three distinct planes: the first two are vertical, but nearly at right angles to one another; the last is horizontal.

Each canal is rather more than half of a circle, and forms at one extremity a dilatation called the ampulla. The canals communicate with the vestibule by *five* openings, one of which belongs to both the superior and posterior canal.

The interior of the vestibule and semicircular canals is lined with a delicate membrane. The cavity formed by this membrane contains a fluid of serous nature. It is known as the *perilymph,* by reason of its surrounding a secondary structure, the labyrinth. This last structure consists of a pair of saccules in the vestibule, and three semicircular saccules whose form is the same as the osseous canals containing them. This membranous labyrinth comprising the saccules just mentioned itself contains a serous fluid, the *endolymph.*

The inner portion of the bony labyrinth is the *cochlea:* so named from its resemblance to a shell. Its base is attached to the internal auditory meatus, while its apex is directed forward and outward. The axis of the cochlea is nearly at right angles to that of the petrous portion of the temporal bone in which it lies. The cochlea is a tube of bone wound around a central axis, each turn successively rising. This bony tube is about one and one-half inches long. Its beginning is connected with the fore part of the vestibule to produce the promontory of the tympanum; it ends in a closed extremity called the *infundibulum.* The central axis just spoken of is termed the *modiolus.* The apex of the cochlea is often called the *cupola.*

The bony canal is divided into two passages, or *scalæ,* by a septum known as the *lamina spiralis,* which projects from the modiolus. The two scalæ communicate with one another only at the top of the cochlea, by an opening: the *hiatus,* or *helicotrema.* That portion of the cochlear canal that is above the septum terminates in the vestibule; hence *scala vestibuli.* The lower portion opens into the tympanum through the *round* window; hence *scala tympani.*

The membranous portion of the septum, or lamina spiralis, consists of two layers: The superior layer is the *membrane* of *Corti,* or *membrana tectoria;* the other is the *membrana basilaris.* These two membranes are placed parallel with one another to contain between them the *organ* of *Corti.* The latter rests upon the basilar membrane.

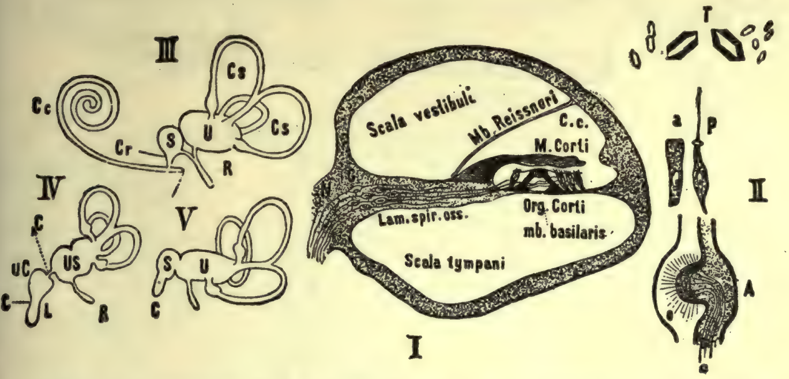


Fig. 311.—Scheme of the Labyrinth and Terminations of the Auditory Nerve. (Landois.)

I. Transverse section of a turn of the cochlea.

II. Ampulla of a semicircular canal. ***a, p,*** **Auditory cells.** ***p,*** **Cell provided with a fine hair.** ***T,*** **Otoliths.**

III. Scheme of the human labyrinth.

IV. Scheme of a bird's labyrinth.

V. Scheme of a fish's labyrinth.

The bony portion of the septum has, upon its superior external surface, a denticulated, cartilaginous substance called the *lamina denticulata.* From the superior surface of the lamina spiralis, and internal to the lamina denticulata, exists a delicate membrane, the *membrane of Reissner.* This membrane divides the scala vestibuli into two passageways, one of which is the *ductus cochlearis.* It contains the essential portion of the auditory apparatus of the cochlea: the organ of Corti. It forms part of the membranous labyrinth.

The membranous labyrinth is a closed sac consisting of semicircular canals, a vestibular portion, and the membranous part of the lamina spiralis. The vestibular portion consists of an expanded body, the *utricle*, and a smaller body, the *saccule*. Within these compartments are two calcareous bodies: the *otoliths*. The vestibular filaments of the cochlear nerve are distributed to the ampullæ, utricle, and saccule. In the first the fibers terminate in elevations called *cristæ acusticæ;* in the last two they end as oval plates,—*maculæ*,—colored by yellow pigment.

Organ of Corti.—The organ of Corti contains the following elements:—

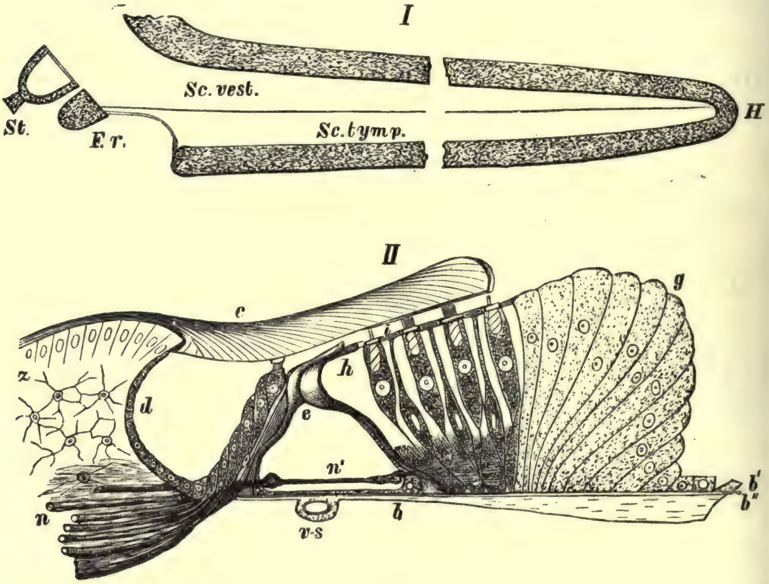


Fig. 312.—Section through the Uncoiled Cochlea (I) and through the Terminal Nerve Apparatus of the Cochlea (II). (Munk, after Hensen.)

I. *Fr.*, Round window. *H*, Helicotrema. *St.*, Stapes.
II. *z*, Huschke's process. *b'*, Basilar membrane. *e*, Corti's arch. *g*, Supporting cells. *h*, Cylindrical cells. *i*, Deiters's hair-cells. *c*, Membrana tectoria. *n*, Nerve-fibers. *n'*, Nonmedullated nerve-fibers.

1. *Arches of Corti.*—They are formed of an internal and external pillar whose pedestals rest upon the basilar membrane. The arches intercept the canal of Corti.

2. *Internal Auditory Cells.*—Inward from the internal pillar of Corti is found a layer of auditory cells. These cells contain nuclei, while their superior extremities terminate in a plateau having long ciliated prolongations; their inferior extremities are in relation with

the basilar membrane and axis-cylinder of the terminal cochlear branches of the auditory nerve.

3. *A Granular Layer* composed of rounded cells.

4. *Cells* in the sulcus spiralis which are cubical in shape.

5. *The External Auditory Cells,* whose structure and arrangement are very similar to the internal cells just mentioned.

6. *The Cells of Deiters, Hensen, and Claudius,* which make a prominence upon the interior of the cochlear canal.

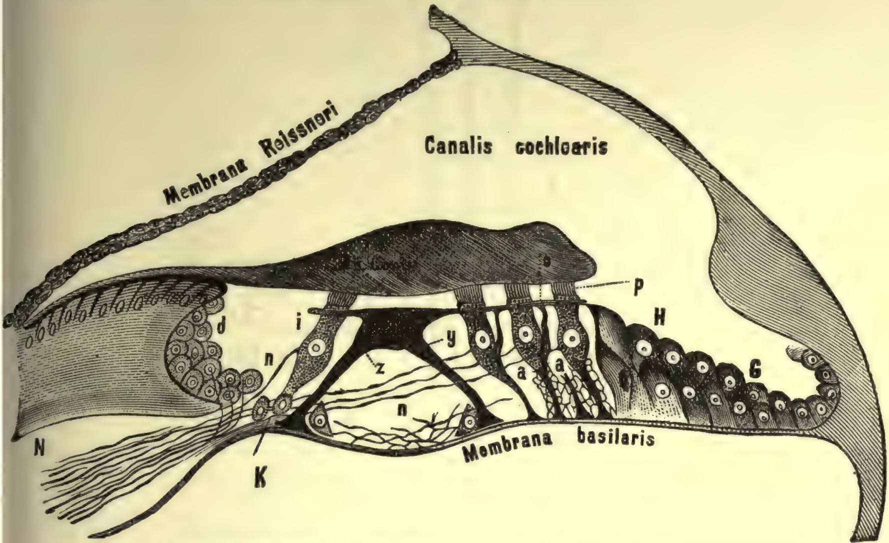


Fig. 313.—Section of the Ductus Cochlearis and the Organ of Corti. (After Landois.)

N, Cochlear nerve. *K*, Inner, and *P*, outer, hair-cells. *n*, Nerve-fibrils terminating in *P*. *a*, *a*, Supporting cells. *d*, Cells in the sulcus spiralis. *z*, Inner rod of Corti. *Mb*, Corti, membrane of Corti, or the membrana tectoria. *o*, The membrana reticularis. *H*, *G*, Cells filling up the space near the outer wall.

7. *Reticular Membrane.*—The membrana reticularis is formed by the superior extremity of the cells of Deiters. It possesses lacunæ which allow the passage of cilia of the cells.

8. *The Membrane of Corti,* or membrana tectoria, is a soft, thick membrane which covers the spiral groove and organ of Corti. Beneath it adheres to the cilia of the auditory cells.

Auditory Nerve.—The auditory nerve consists of two parts: the cochlear, the hearing part, and the vestibular, the tonus part. The cochlear part arises in the spiral ganglion of the cochlea, and, like a posterior root ganglion, sends a branch to the auditory cells in the organ of Corti and a central branch to the cochlear nucleus in the medulla. The cochlear nucleus consists of two parts: the accessory nucleus and the tuberculum acusticum. Hence the first neuron extends from the spiral ganglion to the cochlear nucleus; then the two divisions of the cochlear nucleus—the accessory nucleus and tuberculum acusticum—send out neuraxons to the superior olive; here they are second neurons. The superior olive sends out neuraxons to the lateral fillet; here the third neuraxons make up chiefly the lateral-fillet fibers. These go to the posterior corpora quadrigemina and finally are connected with the seat of hearing in the first temporal convolution.

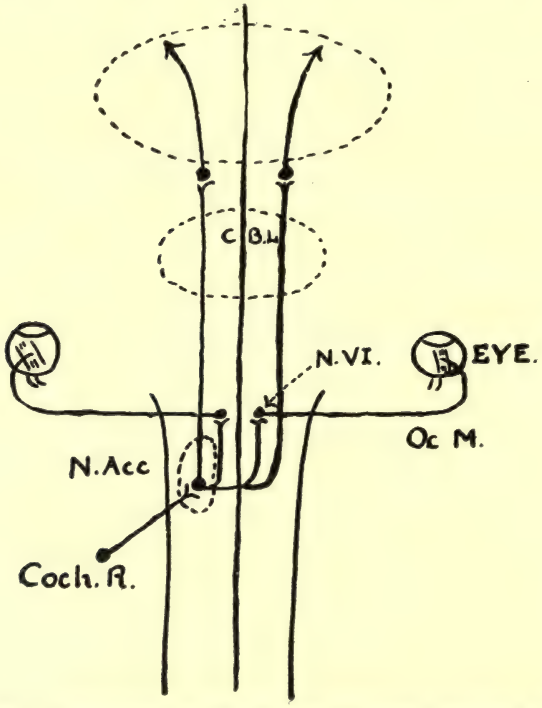


Fig. 314.—Connections of Cochlea with Central Nervous System. (Paton.)

Coch.R, Cochlear root of eighth nerve. *N.Acc,* Tuberculum acusticum and nucleus accessorius sending fibers to the cerebrum (*C.B.*) and to oculo-motor mechanism (*N.VI.*).

The vestibular root arises in Scarpa's ganglion-cells of the labyrinth and goes to the vestibular nucleus.

The vestibular nucleus is composed of the medial, the lateral, or Deiters's, the superior, or Bechterew's, and the nucleus of the descending root. There are connections between the nucleus of Deiters and the nucleus fastigii of the cerebellum. Deiters's nucleus is connected with the vestibulo-spinal tract which runs down the cord to the anterior horns. Fibers from the cerebellar nuclei go by the superior cerebellar peduncle and the red nucleus, and end in the

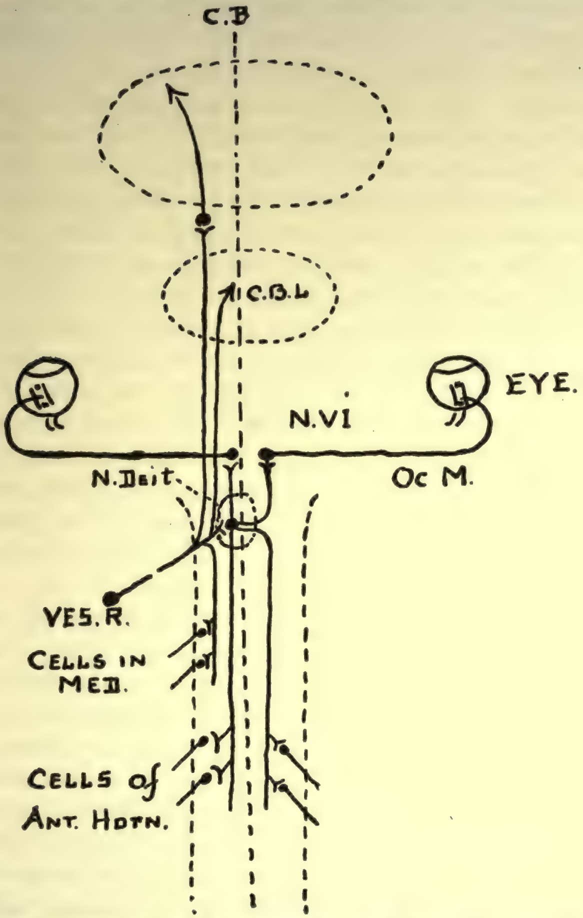


Fig. 315.—Connections of Semi-circular Canals with Central Nervous System. (Paton.)

Ves.R, Vestibular root of eighth nerve sending fibers to C.B (cerebrum) and C.B.L (cerebellum) downwards to center in medulla oblongata (Med), and to Deiters's nucleus (N.Deit), from which fibers pass to oculo-motor mechanism (N.Vi) and to center in the anterior horn of the spinal cord.

cortex of the parietal and central convolutions. Some fibers from the nucleus of Deiters and of Bechterew go by the posterior longitudinal bundle to the nuclei of the motor nerves of the eye. (See equilibratory center of Mills.)

The cochlear nerve is the nerve concerned in hearing.

The vestibular nerve is the nerve concerned in equilibration. It does not have anything to do with hearing.

Membrana Tympani.—The membrana tympani is an elastic, very vascular membrane, which protects the delicate organs of the middle ear against the action of cold coming in from the external ear. It is also specially endowed with a specific sensibility for the contact of special agents, as the scratchings of an insect on its surface cause a peculiar auditory sensation. The membrana tympani is of variable size, according to the species of animal, and is adapted to receive low and high sounds. It is of circular form, and attached by its borders upon a bony circle, the tympanic circle. Its direction is peculiar. It cuts obliquely the axis of the external auditory meatus and this obliquity is favorable to the impact of sound-waves. It is depressed and becomes prominent in the middle, having the arrangement of a depressed cone. Under the shock of sound-waves the membrana tympani vibrates for all sounds in the range of perceptible sounds. Its vibration can be measured by a water manometer inserted into the external auditory canal.

Accommodation of Membrana Tympani.—Since the membrana tympani vibrates in unison with all the external sounds which strike it, it is inferrable that there is a means capable of regulating the tension of this membrane. The shape of the tympanic membrane is peculiarly adapted for transforming weak movements of wide amplitude into strong ones of wide compass. For it is not simply a depressed cone, but the radii are slightly curved with the convexity outward, a shape mainly caused by the elastic fibers maintaining a tension on its inner surface, these being most numerous toward the circumference. The principal regulator of the tension is the tensor tympani. The membrane of the tympanum has no definite fundamental tone; it vibrates indifferently to every sound. The membrana tympani is tense for high sounds and relaxed for low sounds, but these changes in tension are chiefly for the intensity of sound rather than their height, so as to offer a resistance to the shock of sound-waves and obviate the effect of this shock upon the deep and delicate structure of the ear.

The adherence of the membrana tympani to the handle of the malleus, which follows its movements, causes its vibrations to meet with considerable resistance. This diminishes the intensity of the vibrations, and prevents also the continued vibration of the membrane after an external vibration has ceased, so that a sound is not heard much longer than the moment when the exciting cause ceases. The tensor tympani at its base arises from the apex of the petrous portion of the temporal bone and the cartilage of the Eustachian tube, and is inserted into the malleus near its root. The membrana tympani has the handle of the malleus inserted into its layers; and as the malleus and incus move around an axis passing through the neck of the malleus from before backward, the action of the tensor tympani is to pull the membrana tympani inwards toward the tympanic cavity in the form of a funnel, the meridians of which are not straight, but curved with the convexity outwards. This making tense and relaxing the membrana tympani is a kind of accommodating apparatus for receiving and transmitting sounds of different pitch. With different tensions it will respond more readily to sounds of one pitch than to sounds of another.

The tensor tympani receives its motor fibers from the fifth by the otic ganglion, and its movements are purely reflex.

The stapedius muscle is innervated by the facial and exercises an antagonistic action to the tensor tympani. The stapedius draws the stapes outward, whilst the tensor tympani tends to press the stapes into the oval window. The two antagonistic muscles are able to combine in such a manner as to modify the length of the chain of ossicles, and give an amplitude variable to the vibrations.

Hensen has proved that these muscles are reflexly kept in a state of adjustment by the pitch of sound.

Transmission of Sound Waves in the Middle Ear.—The normal and regular means of transmission of sounds is by the chain of ossicles, but it can take place by the air in the cavity of the tympanum, or by the bones of the skull.

The ossicles of the middle ear form, by the articulations which unite them, a broken but rigid chain between the membrana tympani and the oval window. This chain of bones is not always in the same state, for the combined action of the two muscles modifies the length and rigidity of the chain. Pollitzer, by means of very fine pens, has been able to register the movements of the bones. In rarefaction of the air in the auditory meatus, as with the pneumatic speculum, there is no danger of pulling the stapes out of the oval window, for the incus only follows the malleus for a certain distance, the latter completing its motion by gliding in the joint. The destruction of the chain of bones does not necessarily cause deafness, any more than perforation of the membrana tympani, as long as the stapes is preserved. If the stapes is torn out there is deafness, because the perilymph escapes into the middle ear and it is not able to transmit sound-waves to the membranous labyrinth.

The bones of the head also conduct sounds, as is easily proved by closing the ears with your fingers and putting a watch between the teeth. The intervention of the bones of the skull in the transmission of sounds is made use of in the audiphone for the deaf, where a rod, which terminates in a large disk spread out to receive sounds, is held between the teeth.

Transmission of Sounds by the Air in the Middle Ear.—In the normal state the air enclosed in the tympanic cavity plays an insignificant part in the transmission of sound-waves, but its intervention is inevitable when the chain of ossicles has been destroyed. It is probable that it conveys the sound to the round window.

Eustachian Tube.—The air enclosed in the middle ear is constantly kept in an equilibrium of pressure with the external air by the intermittent patency of the Eustachian tube, which extends between the cavity of the tympanum and the pharynx. The Eustachian tube is opened in each act of deglutition, by the salpingo-pharyngeus and the dilator tubal muscles. If the air is enclosed in the tympanic cavity, the oxygen goes to the blood and the carbon dioxide is given off, but the amount of carbonic acid given out is less than the amount of oxygen removed, so that the total quantity of gases in the tympanic cavity is reduced, the air is rarefied, and the membrana tympani, on account of the vacuum, presses upon the chain of ossicles, which are immobilized and do not readily transmit any vibrations. By a forced expiration, the oral and nasal cavities being closed, followed by an act of deglutition, air may be driven into the tympanic cavity and a crackling noise will be heard. This is Valsalva's positive experiment. A forced inspiration accompanied by deglutition will draw air from the cavity, again causing a crackling noise, the negative experiment of Valsalva. In the positive experiment of Valsalva the membrana tympani bulges outward; in the negative experiment it bulges inward; and in both, from the extreme tension of the membrane, there is a partial deafness for high-pitched sounds.

Permanent closure of the Eustachian tube by catarrhal conditions is the most frequent cause of deafness. Closure of the tube, except in deglutition, is necessary for the transmission of sound-waves in the middle ear. Deglutitions periodically open the Eustachian tube and form an auxillary function to that of hearing. These acts follow each other at short intervals and are repeated often during the day, even during sleep.

In a deep mine where the atmosphere is considerably more dense than that on the surface, the uninitiated is instructed to swallow every few minutes. By so doing he maintains an equable pressure upon both sides of the membrana tympani.

The secretory nerve of the submaxillary gland is the chorda tympani, which passes through the middle ear and may be considered as a proof of the functional unity which belongs to the salivary secretion and hearing.

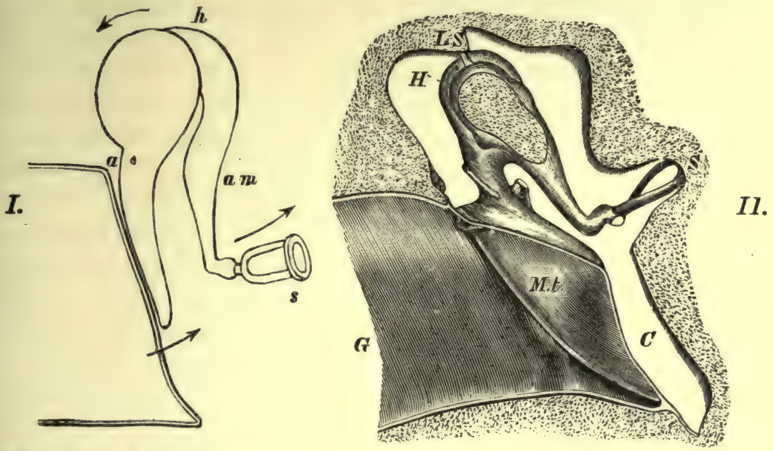


Fig. 316.—I. The Mechanics of the Auditory Ossicles. (After HELMHOLTZ.) II. Section of the Middle Ear. (MUNK, after HENSEN.)

I. *a*, Malleus. *h*, Incus. *am*, Long process of incus. *s*, Stapes. The arrows show the direction of motion.

II. *G*, External auditory canal. *M.t.*, Membrana tympani. *C*, Tympanum. *H*, Malleus. *L.S.*, Superior ligament. *S*, Stapes.

Movements of the Ossicles.—To the tympanic membrane is attached the handle of the malleus, whilst projecting above the edge of the membrane, into the tympanic cavity, is the head of the bone. Helmholtz states that the malleus-incus articulation, in its action, may be compared with the points of the Breguet watch-keys, which have rows of interlocking teeth which offer scarcely any resistance to revolution in one direction, but allow no revolution in the other. Hence, when the handle of the malleus moves inward toward the tympanic cavity, the incus and its long process, which is parallel with the handle of the malleus, also passes inward, from the fact that the head of the malleus pulls the articulating surface of the incus outward. The long process of the incus and the handle of the malleus vibrate in the same direction. When the long process of the incus moves inward it gives an impression to the stapes, with which it articulates almost at right angles. The stapes cannot be torn out of the oval window by the Siglé pneumatic speculum when the tympanic membrane is drawn outward, as the incus only follows the malleus for a certain distance, the malleus sliding in the joint to complete its motion. The malleus and incus are fixed by ligaments in such a way that motion is only possible in to-and-fro vibrations around the so-called axis of rotation, one end of which is found at the origin of the anterior part of the anterior ligament of the malleus, and the other end in the short process of the incus. The ossicles of the ear act like a compound lever; the short process of the incus is the fulcrum; the power is applied to the umbo, in which the handle of the malleus ends; and the resistance is the base of the stapes. The length of the handle below the axis of the malleus is one and one-half times that of the head above the axis. But the range of excursion is only two-thirds that of the handle and drumhead, whilst the power of movement of the head of the malleus will be one and one-half times more than that of the handle. By this means, according to Helmholtz, vibrations are diminished in extent but increased in force. The chain of ossicles vibrates as a whole, and not by molecular vibration. The tympanic membrane is twenty times the size of the oval window; hence the movement of the membrane of the oval window is smaller in extent, but about thirty times greater in power. When sound impinges against the tympanum, the tympanic membrane moves inward with the attached handle of the malleus, and the head of the malleus moves outward. The incus follows these movements; the body of the incus swings outward and the long process moves inward, which pushes the stapes into the oval window.

Thus the ossicles and the fluid in the labyrinth do not form a mass vibrating independently, but as one body.

Tensor Tympani.—The tensor tympani reflex has its sensory nerves from the trigeminus and its motor nerve from the same source. When one tensor tympani contracts, the tensor of the opposite side also contracts.

In rare cases the tensor tympani is under the control of the will.

A man who is absolutely deaf in one ear has great difficulty in recognizing the direction of sound.

It will be recalled by the student that all of the spaces and compartments of the internal ear, or labyrinth, are filled with perilymph, and that in this fluid float saccules containing endolymph fluid. So intimately are all of the parts of the labyrinth associated that any vibration of its contained fluid at one part is promptly propagated to every other portion. The vibrations of the fluid striking upon the tiny nerve-filaments act as stimulants whose impressions are carried to the center of hearing, where the impressions are recognized as sound.

To epitomize: The sonorous waves collected by the auricle to pass through the external auditory meatus and along its canal strike the surface of the membrane of the tympanum. It becomes tense, vibrates in unison, and then communicates its vibrations through the ossicles and contained air in the tympanum to the oval window.

From here the vibrations are carried over the vestibule, semicircular canals, and labyrinth to the perilymph. From this the vibrations are transmitted through the membranous walls of the sacculus to the endolymph. Vibrations also pass from the vestibule to the scala vestibuli of the cochlea, and, through the helicotrema, descending the scala tympani, end as an impulse against the membrane of the round window.

Most of the organs of special sense contain a "specially modified epithelium" for the reception of the particular kind of stimulus peculiar to each other. Nor is the sense of hearing different from the others. It also has its tissues representing "specially modified epithelium" in which lie the terminal filaments of the auditory nerve. These tissues are so constituted that they receive the "waves of sound" which generate auditory impulses in the auditory nerve. These last, when conveyed to the brain, are developed into auditory sensations.

The vibrations of elastic bodies produce *condensation* and *rarefaction* of the enveloping atmosphere. That is, there are developed waves whose particles vibrate longitudinally. These waves are usually spoken of as sound-waves.

Normally, then, the auditory nerve may be stimulated by sonorous vibrations which set into motion the end-filaments of the acoustic nerve. The filaments are distributed over the inner surface of the membranous labyrinth, upon the membranous expansions of the cochlea, and in the semicircular canals. The excitement of the filaments is really mechanical in nature, due to the wavelike motion of the serous fluid of the membranous labyrinth.

It is common to divide auditory stimuli into those which are caused by *noises* and those caused by *musical* sounds. It is a feature peculiar to musical sounds that the vibrations which form them are *periodical* and that they recur at regular intervals. When neither of these two conditions is present, there results a noise. From the sensory impulses to which the several vibrations give rise are generated our sensations of noise or of sound.

To produce a sensation certain conditions in the excitation of the auditory nerve are necessary.

The sound-wave must exist for a certain length of time; it must not be greater than $^1/_{30}$ nor less than $^1/_{40000}$ second. In the piano the lowest base (C, 33 vibrations) and the highest treble (C, 4224 vibrations) exist. A certain number of impulses must be made within a given interval of time to excite a sensation of tone. The lower limit is about 30 vibrations, the upper limit about 40,000, per second. Visual sensations separated by less than a tenth of a second are fused, but auditory sensations separated by $^1/_{133}$ second remain distinct.

Theory of Hearing.—If you sing a note into a piano, the cords of the piano tuned for this note only respond. Now the basilar membrane is supposed, like a harp, to represent a series of cords which, like the piano-strings, respond to the sounds striking them. This membrana basilaris is striated in a radiating direction, and these striations increase as it ascends toward the helicotrema. Unlike the harp, the cords are joined together by their edges; but, as they are stretched only in a radiating direction, they can vibrate as though they were separate cords. Now, the cords are very short, being at most not over $^1/_{12}$ inch in length; so that they would be expected only to vibrate for high sounds; but it must be remembered that these cords are weighted with the arches and cells of Corti, which lower their sound. Hence we have a series of cords in the basilar membrane vibrating separately to musical sounds. We know that there are in man about 3000 arches of Corti, and as at least two of the cords correspond to an arch of Corti, we have 6000 cords. Now, the scale of musical sounds extends to seven octaves, and we have 400 arches of Corti to 1 octave. In 1 octave there are 12 semitones, and we have 66 cords corresponding to a semitone; so that we have sufficient cords to vibrate in unison with all possible musical sounds.

When the sound-waves vibrate the cells of Corti they make the terminal filaments of the cochlear nerve vibrate, because they are in relation with the cells of Corti. The analysis of sounds takes place in the brain.

Binaural Audition.—The hearing of a single sound with both ears may be due to habit or to the connection in the nerve-centers of the fibers connected with both ears. Undoubtedly binaural audition facilitates our knowledge of the direction of sound, since each ear has its own axis and direction.

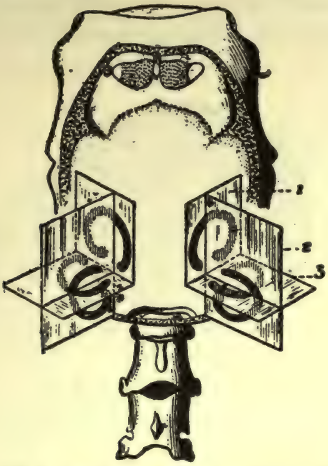


Fig. 317.—Schema of the Semi-circular Canals, the Posterior Part of the Skull Removed. (HEDON, after EWALD.)

In the plane 1 lies the anterior canal. In the plane 2 the external canal. In the plane 3 the posterior canal.

We combine binauricular audition, just as we judge of the relief of objects in binocular vision (stereoscopic vision), to determine the direction of sounds. The tympanic membrane may be looked upon as an organ of pressure-sense by variations of air-pressure, even when sound-sensations are not produced.

A blind man has been able to state correctly that he has passed a fence, and whether it be of solid board or of open picket. It may be stated that the membrana tympani is the outward organ of pressure-sense, by which we know more or less the position of objects independent of the sensations of sight and hearing. The air is in endless movement, and its waves, striking against various objects, must be impinged against the drumhead with an intensity dependent upon their position and the physical properties of the bodies reflecting it.

Auditory Sounds.—All auditory sensations are immediately referred to the external air. When your head is immersed in water, then the auditory sensations are not projected externally, but seem to arise in the ear.

Auditory Judgment.—The auditory sensations inform us of the nature, distance, and relative situation of bodies. The judgments draw their exactness from associations established in previous experiences between those of hearing and the other senses. When we hear a particular instrument, the sensation we experience calls up a picture of all its qualities which, from our past experience, we know belong to that instrument. The appreciation of the distance of a body by its sound results from thousands of experiences between auditory impressions of that body and the visual impressions. The auricle has an important part in the determination of the direction of sounds, causing an inequality of impressions which strike the two ears.

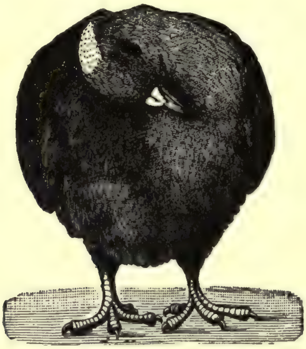


Fig. 318.—Semi-circular Canals on Right Side Destroyed. Commencing rotation of head of pigeon about five days after the operation. (After Ewald.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

Semicircular Canals.—The semicircular canals are, through the vestibular nerve and the cerebellum, the most important agents in the preservation of equilibrium. When in a pigeon the horizontal canals are divided, the head moves from left to right and from right to left, with nystagmus and a tendency to revolve on its vertical axis. When the inferior vertical or posterior canals are divided, the head oscillates from front to rear; the animal has a tendency to fall backward. A section of the superior vertical canal causes the head to oscillate from front to rear, with a tendency to fall forward. A section of all the canals is followed by contortions of the most bizarre nature. After a destruction of all the canals the animal cannot maintain his equilibrium.

Similar phenomena have been observed in man in disease of the semicircular canals, known as Ménière's vertigo. In the fixed position of the head there is equilibrium, but with each movement the varying tension of the liquid in the ampulla changes and irritates the hair-cells.

The horizontal, semicircular canals form the arc of a circle, with an ampulla at each end. In rotation of the head to the right, the endolymph in the ampulla of the right horizontal canal will accumulate in the ampulla because the membranous canal is very narrow. This will cause a high pressure in the ampulla.

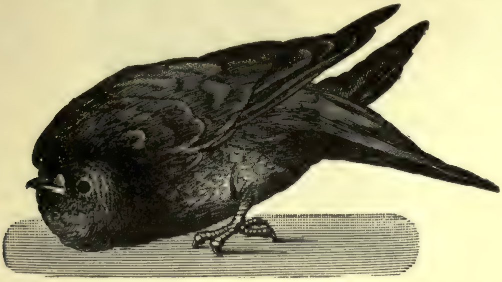


Fig. 319.—Twisting of the Head of a Pigeon twenty days after removal of all the semi-circular canals on the right side. (Ewald, J. R.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

These ampullæ and canals are, then, sensory organs, and give the animal an idea of the position of his head in space. Now, as the canals are at right angles to each other according to the three dimensions in space, their section makes the animal unable to know the position of his head and thus produces vertigo. Cyon's theory that the semicircular canals give us a series of unconscious sensations as to the position of our heads in space. (See cerebellum.)

Ewald holds that all the muscles of the body are kept in a state of tonus by means of the semicircular canals, and that injury to them affects those muscles whose movements are most delicate, such as those of the eye and larynx. The loss of tonus may be explained for some of the muscles by disturbances in the reflex arc of the vestibular nerve, Deiters's nucleus, and the vestibulo-spinal tract. Here is a reflex between the semicircular canals and the muscles of the body innervated by the anterior horns which have the vestibulo-spinal tract connected with them.

The fibers from Deiters's nucleus go to the nuclei of the motor nerves of the eye by the posterior longitudinal bundle; hence the nucleus of Deiters may be a reflex center, with the semicircular canal on one side and the fibers from Deiters's nucleus to the motor nuclei for the eye-muscles on the other side. Destruction of the semicircular canals would thus cause loss of tonus in the eye-muscles.

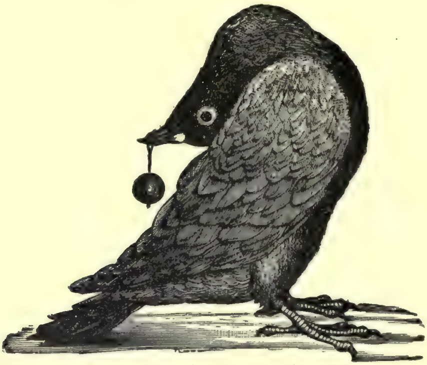


Fig. 320.—Position of Pigeon's Head after removal of all the semicircular canals on both sides. (EWALD, J. R.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

A 20-gram lead ball fastened to beak with wax, which cannot be moved, owing to weakness of the muscles of the neck.

Utriculus and Sacculus.—The utriculus and sacculus, small sacs, also contain hair-cells, and lying among them are the otoliths, consisting of crystals of calcium carbonate. Breuer states that these sacs give us information when the head is at rest and when it is making slow rotary movements. Thus they aid the function of the semicircular canals. In this view, the otoliths mechanically stimulate the hairs.

CHAPTER XIX.

SPECIAL SENSES (Concluded.)

VISION.

Those bodies are said to be luminous which especially affect the organ of vision. Some are luminous in themselves, others become so by reflection. Since there is no direct contact between the visual apparatus and the object which makes the impression, and since the distance which separates them is often infinite, it is impossible not to admit the existence of a particular intervening agent between the center of radiation and the eye. This agent is *ether*.

How Does Light Transmit Itself?—The accepted theory to-day with regard to its propagation is the *undulatory,* or *wave, theory.* Its doctrines make light, like heat and sound, a *mode* of *motion.*

A luminous body is one whose particles are in a state of vibration. That they may give rise to a luminous impression it is necessary that they be transmitted to the eye. Ordinarily the atmospheric air is the usual medium for the transmission of the vibrations of a sounding body to our ears. However, a luminous body does not become invisible in a *vacuum,* as does a sounding body become inaudible. Hence, there must be supposed the existence of a highly elastic medium that pervades all spaces and all bodies. To this especial medium luminous bodies communicate their vibrations to be transmitted with enormous velocity. This medium is known to physicists as *ether.*

Suppose a luminous body isolated in a gas or suspended in a vacuum; it will be visible in all directions. Imagine, also, a point of space lighted up by its radiations. The line which joins this point to one of the elements of the luminous body represents the direction of a *ray* of light. So long as no obstruction intervenes the ray of light pursues an even, straight course. Should, however, a mirror intercept its path, the greater portion of it will be bent out of its regular course. That is, it is *reflected.* In all cases of reflection it is well to remember that "the angle of reflection always equals the angle of incidence."

Again, the passage of light through transparent media of various densities presents peculiarities: its straight course is modified—broken. To convey a conception of this phenomenon the term *refraction* is used.

The organ of sight, the eye, is constructed upon the principles of the camera obscura. In the latter the collecting lens unites the light impressions at the back of the apparatus to form upon the ground-glass plate a diminished and reversed image of external objects.

Structure.—The eye is composed of three concentric *coats* (*sclerotic, choroid,* and *retina*), the *aqueous* and *vitreous humors* and the *crystalline lens.*

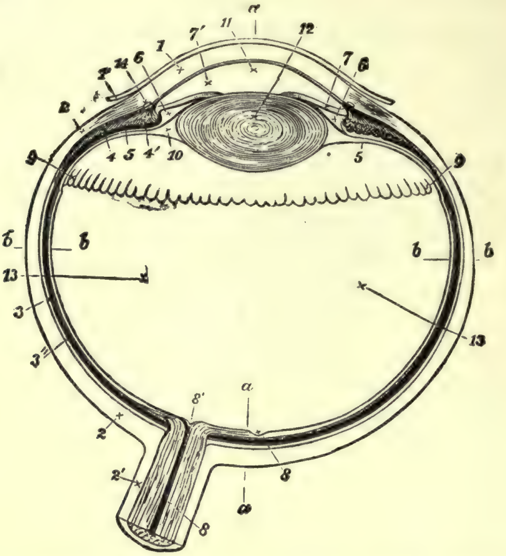


Fig. 321.—Diagram of a Horizontal Section through the Human Eye. (Yeo.)

1, Cornea. 2, Sclerotic. 3, Choroid. 4, Ciliary processes. 5, Suspensory ligament of lens. 6, So-called posterior chamber between iris and lens. 7, Iris. 8, Optic nerve. 8', Entrance of cerebral artery of retina. 8'', Central depression of retina, or yellow spot. 9, Anterior limit of retina. 10, Hyaline membrane. 11, Aqueous chamber. 12, Crystalline lens. 13, Vitreous humor. 14, Circular venous sinus which lies around the cornea. *a-a,* Antero-posterior axis of bulb. *b-b,* Transverse axis of bulb.

The *first,* or outside, coat of the eye is opaque in all of its parts except a small anterior segment. This area, which is about one-sixth of the entire circumference, is perfectly transparent. The dense, opaque part is known as the *sclerotic;* the transparent portion is the *cornea,* which is the most anterior portion of the sclerotic.

The sclerotic is thickest behind, in the neighborhood of the part pierced by the optic nerve, which is placed about a tenth of an inch inside of the antero-posterior axis. The sclerotic thins a little as it passes forward, and is weakest about two lines from the cornea; the anterior portion again increases in thickness.

Cornea.—It is joined to the sclerotic coat by direct continuity of tissue. The tissue of the cornea absorbs water readily and becomes opaque after death. The cornea has five layers. The *first,* or anterior, *epithelial layer* is composed of several layers of epithelial cells; the deepest are cylindrical, which pass over into the lower polygonal cells, which, on the surface, become flat, nucleated cells. At the edge of the cornea this epithelium becomes continuous with that of the conjunctiva. *Second layer:* the anterior elastic lamina (of Bowman) is formed by the superficial part of the proper structure of the cornea, which is denser than the rest of the tissues and free from corpuscles. This layer is strongly developed in man and is a homogeneous refractive membrane. Fibrils can be demonstrated in it by means of certain reagents. *Third layer:* the substantia propria, or the cornea proper, forms the main mass of the cornea. It consists of fibrils of connective tissue bound together in flat lamellæ (about 60 in number). The fibrils run in various directions, and cross each other at various angles. Between the lamellæ are canals and spaces which contain a serous fluid. In these spaces are found the connective-tissue cells, having many processes and large nuclei, around which the serous fluid trickles to carry nutriment to the surround-

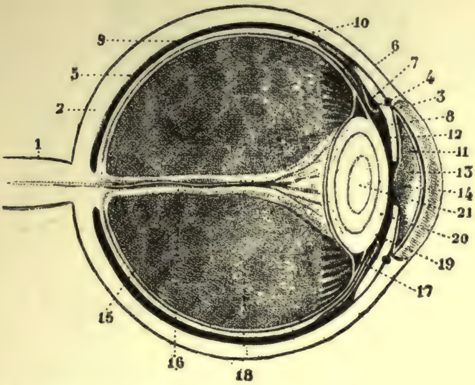


Fig. 322.—Anterior-posterior Section of the Eyeball. (Leveillé.)

1, Optic nerve. 2, Sclerotic. 3, Cornea. 4, Spaces of Fontana. 5, Choroid. 6, Ciliary muscle. 7, Ciliary processes. 8, Iris. 9, Retina. 10, Jacobs's membrane. 11, Anterior chamber. 12, Posterior chamber. 13, Pupillary area. 14, Aqueous humor. 15, Hyaloid membrane. 16, Canal of Stilling. 17, Canal of Petit. 18, Vitreous humor. 19, Capsule of the lens. 20, Fluid of Morgagni. 21, Lens.

ing tissue. By the chloride of gold method a picture is obtained of this system of canals. *The fourth layer:* the posterior elastic layer, or membrane of Descemet. This lamina is about $^1/_{2500}$ of an inch thick, firm, refractive, and homogeneous in structure. When pieces of this layer are separated, they curl up with the attached surface innermost. At its circumference the lamina breaks up into bundles of fibers, some of which form the pillars of the iris. To these radiating and anastomosing bundles of elastic fibers prolonged from the circumference of Descemet's membrane has been given the name

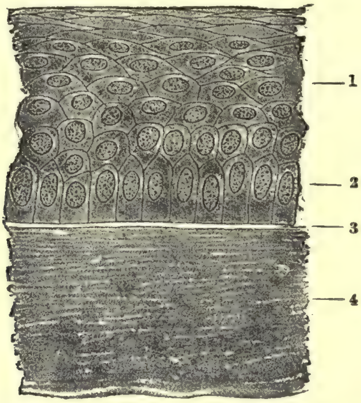


Fig. 323.—Section through the Human Cornea. (Böhm and Davidoff.)

1, Anterior epithelium. 2, Basal cells. 3, Bowman's layer. 4, Substantia propria.

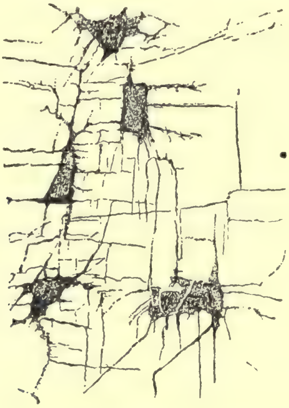


Fig 324.—Corneal Corpuscles of Dog. (Böhm and Davidoff.)

of pectinate ligament. *The fifth layer* of the cornea is the posterior epithelial layer, composed of low, hexagonal cells. The epithelium is deficient at the circumference in the interval between the pillars of the iris. The openings formed are mouths of cavernous spaces (the spaces of Fontana), which lead into the circumferential channel (canal of Schlemm), through the intervention of which the aqueous chamber is placed in connection with the canal of Schlemm, which is a lymphatic channel. The cornea contains no blood-vessels. The corneal nerves enter into the substantia propria of the cornea, where they lose their medullary sheaths and form four plexuses at different levels:—

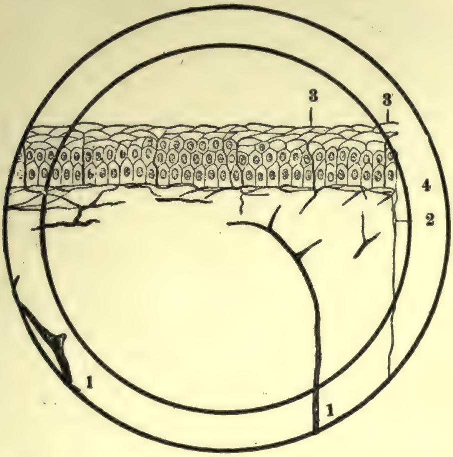


Fig. 325.—Corneal Nerves of the Pig. (Rollet.)

1, 1, Larger nerves. 2, Plexus beneath Bowman's layer. 3, 3, Terminal twigs ascending through the epithelium. 4, Sub-epithelial plexus.

1. The ground plexus, in the deep layer of the substantia propria.
2. The subbasal plexus.
3. The subepithelial plexus.
4. The intraepithelial plexus, which consists of fine fibers running between the epithelial cells, ending in knoblike terminations.

Choroid.—The dark-brown choroid coat is the vascular coat of the eye. It consists of two parts, which are continuous with one another—the choroid and the iris. The choroid is composed of several layers. Externally it is bounded by a nonvascular membrane, the lamina supra choroidea. The arteries groove the sclerotic coat before passing into the choroid. After entering its substance they go beneath the veins, while the latter (vasa vorticosa) receive their tributaries as curved branches arranged in a peculiar form, which has been compared to the branching of a weeping willow, and form four or five large trunks, which pierce the sclerotic half way between the optic nerve entrance and the edge of the cornea. In the inter-

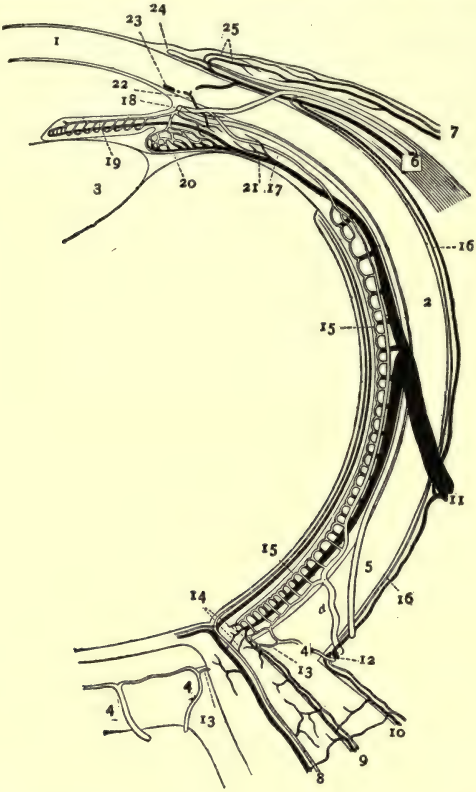


Fig. 326.—Diagram of the Vessels of the Eye. (Leber.)

1, Cornea. 2, Sclera. 3, Lens. 4, 4, Short ciliary nerves. 5, Long posterior ciliary artery. 6, Anterior ciliary artery and vein. 7, Posterior conjunctival artery and vein. 9, Vessels of the internal optic sheath. 8, Vessels of the external optic sheath. 11, Vena vorticosa. 12, Posterior short ciliary vein. 13, Branch of short posterior ciliary artery to the optic nerve. 14, Anastomosis of choroidal vessels with those of the optic nerve. 15, Chorio-capillaris. 16, Episcleral branches. 17, Recurrent choroidal artery. 18, Large arterial circle of iris (transverse section). 19, Vessels of iris. 20, Ciliary process. 21, Branch of vena vorticosa from the ciliary muscle. 22, Branch of anterior ciliary vein from the ciliary muscle. 23, Canal of Schlemm. 24, Plexus of the corneal margin. 25, Anterior conjunctival artery and vein.

vals between the vessels are elongated, stellate pigment-cells. The inner part of the choroid is formed mainly by capillary blood-vessels (tunica Ruyschiana vel chorio-capillaris). This reaches to one-eighth of an inch from the corneal margin, where its vessels join those of the ciliary processes. On the inner surface of the tunica Ruyschiana is a structureless membrane, the membrane of Bruch, which lies next to the pigmentary layer of the retina. The choroid coat ends anteriorly in the ciliary processes and the iris. The ciliary processes consist of about seventy to eighty ridgelike processes running meridionally. They are arranged around the lens, and toward the outside the ground-substance of the processes borders on the ciliary muscle. They have the same structure as the choroid, and contain very numerous blood-vessels, derived from the anterior ciliary arteries.

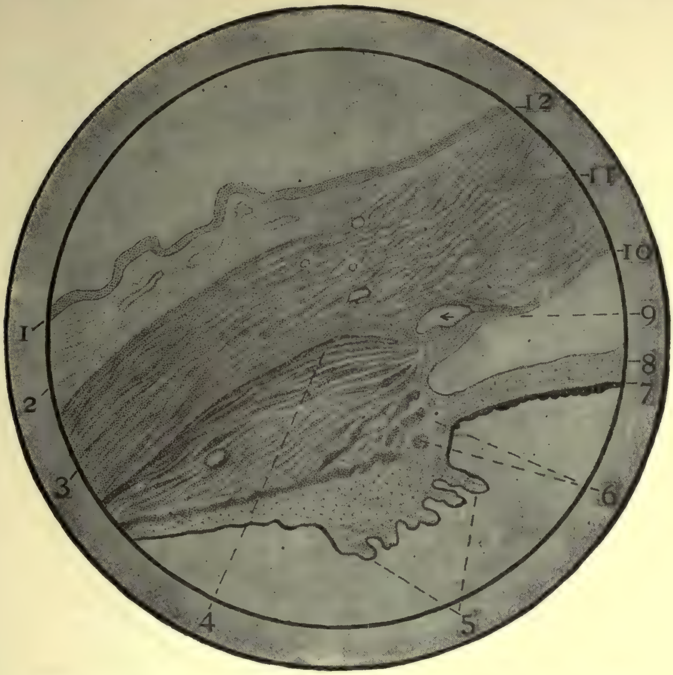


Fig. 327.—Meridional Section of the Human Ciliary Body. (Böhm and Davidoff.)

1, 2, Conjunctiva. 3, Sclera. 4, Meridional fibers of the ciliary muscle. 5, Ciliary processes. 6, Circular fibers of the ciliary muscle. 7, Iris pigment. 8, Stroma of iris. 9, Canal of Schlemm. 10, Membrane of Descemet. 11, Cornea. 12, Corneal epithelium.

Uses.—By reason of its vascularity the choroid is destined to nourish the all-important and underlying retina. By reason of its elasticity and contained musculature the choroid maintains intra-ocular pressure. The pigment of the choroid is believed to serve a dioptric purpose: that of absorbing the superfluous rays of light which pass through the eyeball on their way to the retina. Their absorption prevents dazzling and interference with vision.

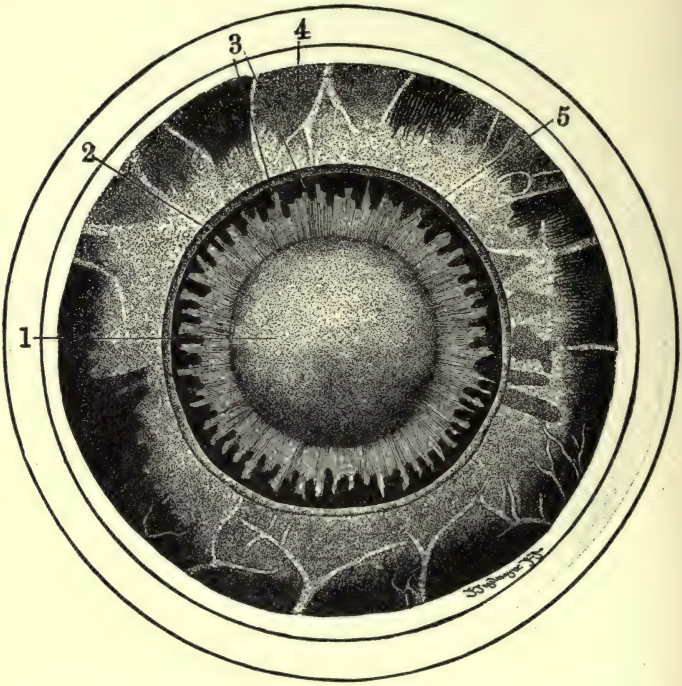


Fig. 328.—Dissection of the Zonula. (After SCHULTZE.)

1, Lens. 2, Cut surface of iris. 3, Ciliary processes. 4, Choroid. 5, Zonula.

Ciliary Muscle.—The fibers of this muscle can be divided into three parts: (1) The strongest layer is nearest the sclerotic. It is composed of a thick layer of fibers having a meridional direction, which extend backwards into the choroid. (2) The second part of the muscle contains fibers which are less intimately connected with each other. Their direction deviates more, and they radiate towards the center of the ocular globe. These fibers terminate near the posterior surface of the ciliary body. (3) The third part of the ciliary muscle is represented by the ring-muscle of H. Müller, and is much developed in hypermetropic eyes, and atrophied or absent in myopic eyes. It is composed of circular fibers, which form a ring parallel with the base of the cornea. The ciliary muscle arises from the sclerotic close to the cornea; its fibers are inserted into the pectinate ligament, and extend to be attached to the choroid, as has just been described.

Ciliary Body.—This includes the ciliary processes and the ciliary muscle.

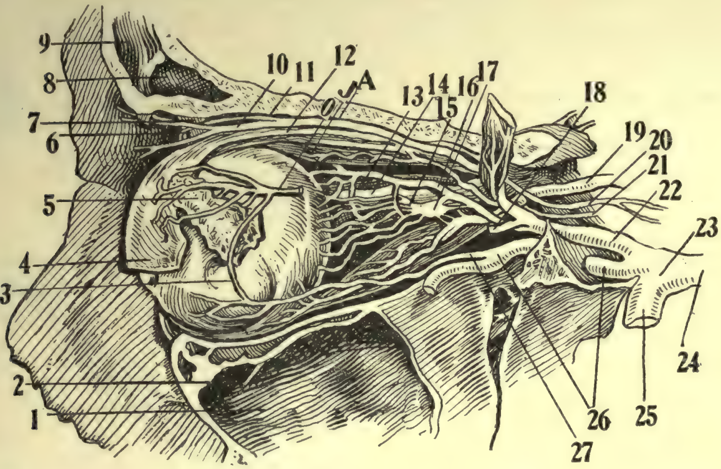


Fig. 329.—Lateral View of the Orbit, Showing the Nerves. (DEAVER.)

1, Antrum. 2, Bristle in the antrum. 3, Loop between orbital and lacrimal nerves. 4, Tarsal plate. 5, Lacrimal gland. 6, Tendon of superior oblique. 7, Pulley of the same. 8, Infundibulum. 9, Frontal sinus. 10, Supra-orbital nerve. 11, Supra-trochlear nerve. 12, Levator palpebræ muscle. *O*, Lacrymal nerve. *J*, Superior rectus muscle. *A*, Frontal nerve. 13, Internal rectus muscle. 14, Optic nerve. 15, Short ciliary nerve. 16, Nasal nerve. 17, Ciliary ganglion. 18, Lacrimal nerve. 19, Motor oculi nerve. 20, Patheticus nerve. 21, Abducens nerve. 22, Ophthalmic division of the fifth nerve. 23, Gasserian ganglion. 24. Fifth nerve. 25, Inferior maxillary nerve. 26, Superior maxillary nerve. 27, Orbital nerve.

Iris.—This body is to be considered as a process of the choroid. It is made up of four layers: (1) The anterior epithelium, made of flat cells, which cover the anterior surface of the iris. (2) The stroma of the iris, which consists of connective tissue which contains numerous blood-vessels, which are radially arranged and have no muscular sheaths. In this part of the iris the smooth muscle-cells are collected to form the sphincter and dilator muscles of the pupil. The sphincter muscles are arranged circularly around the edge of the pupil. The dilating muscles run in a radial manner. The coloring matter which is found in the connective tissue of the stroma of the iris, and its varying quantity, give the color to the iris. (3) The posterior limiting layer, or a portion of Bruch's membrane. (4) The pigment layer (uvea). This is made up of two layers of cells; the posterior layer is cubical and full of pigment, the anterior layer is flat and contains only a small amount of pigment. This pigment-layer is a continuation anteriorly of the pigment-layer of the retina. The color of the iris is due to pigmented connective-tissue corpuscles, especially in brunettes. The artery and veins of the iris lie at its periphery.

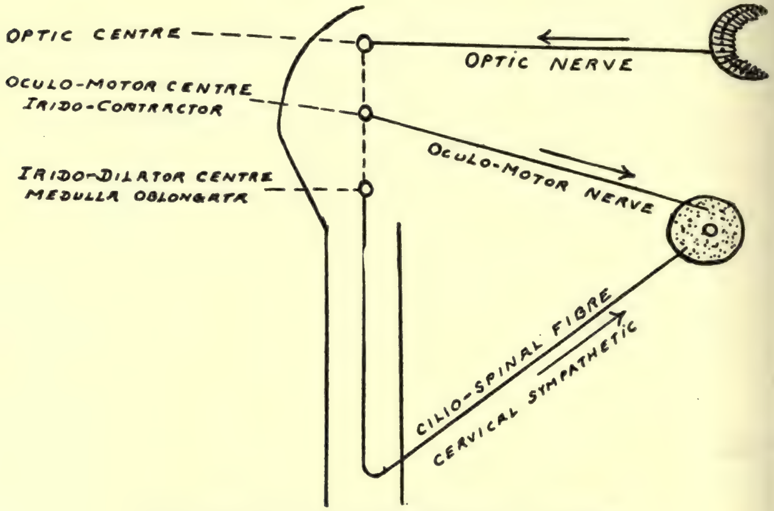


Fig. 330.—The Nervous Mechanism of the Iris.

The pupil is made smaller by contraction of its circular fibers. These belong to the *smooth* type of muscle-fibers and are innervated by the *oculomotor* through the medium of its ciliary branches.

The pupil enlarges through contraction of the radiating fibers of the iris. It is innervated by the ciliary branches derived from the great sympathetic. Sensory nerves are present, coming from the first branch of the fifth, or trigeminus.

Hence, stimulation of the oculomotor, as well as cutting the sympathetic nerve in the neck, or trigeminus, produces *contraction* of the pupil. Irritation of the sympathetic causes the pupil to *dilate*. The normal contraction and dilation of the pupil are *reflex* movements that are caused by the rays of a very strong or very faint light striking the retina. From the retina the impression is conveyed by the optic nerve to the anterior corpora quadrigemina and then to the oculomotor nucleus and by its nerves to the iris. It is not due to the direct action of light upon the iris itself.

The following cause changes in the diameter of the pupil:—

Contraction of Pupil.—Stimulation of optic nerve; stimulation of third cranial nerve; section of fifth cranial nerve; section or paralysis of the cervical sympathetic; light acting on retina; accommodation for a near object; myotics (eserin, stimulation of the ends of oculomotor); anæsthetics (at first).

Dilatation of Pupil.—Section of the optic nerve; paralysis of third cranial nerve; stimulation of fifth cranial nerve; stimulation of sympathetic; stimulation of sensory nerves; mydriatics (atropin, by paralyzing the ends of oculomotor); dyspnœa, asphyxia; anæsthetics (at the end).

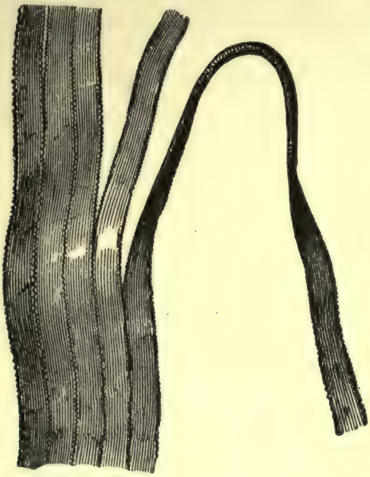


Fig. 331.—Isolated Lens Fibers. (J. Arnold.)

Meltzer and Auer have shown that, with the superior cervical ganglion present, adrenalin does not act on the pupil. When the ganglion is removed, then adrenalin dilates the pupil. I have confirmed this statement.

The Crystalline Lens.—The lens is situated behind the iris, and enclosed in a distinct capsule. The lens consists, in the beginning, of cylindrical cells, which in the course of development increase in height, until exceedingly long cells are formed. The lens-fibers are flattened hexagonal prisms, which are thickened at their posterior ends. They run in a meridional direction from the anterior surface backward, joined by a small quantity of cement substance. The outer fibers have oval nuclei, whilst in the center of the lens no nuclei are found. The capsule of the lens is thicker on the anterior surface than on the posterior. It is a clear, refractive membrane, nonvascular. Between the anterior surface of the lens and the capsule there is a single layer of cubical, nucleated cells. The radius of curvature of the anterior surface of the lens varies with the accommodation for distant vision. It is about 10 millimeters to 6 millimeters in near point of distinct vision.

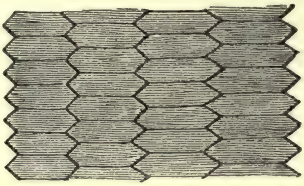


Fig. 332.—Transverse Section of Lens Fibers. (J. Arnold.)

Cataract.—Normally the lens is transparent. When it becomes opaque for any reason, then there results the condition known as cataract. This condition is artificially produced in frogs by the injection of grape-sugar. Cataract in diabetes is from the same cause.

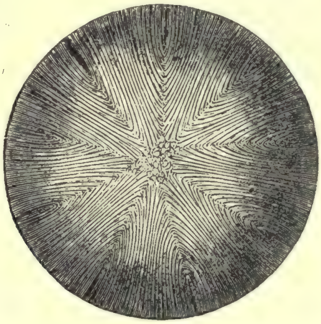


Fig. 333.—Anterior Surface of the Lens of an Adult. (J. Arnold.)

The Retina.—The retina contains the terminations of the optic-nerve fibers. It ends at the pupillary border of the iris. The optical part of the retina ends in the ora serrata, a zigzag line in the vicinity of the ciliary body.

Rods and Cones.—Each rod consists of a rod and a rod-fiber, the fiber containing the nucleus. The rods are cylindrical and elongated. They are divided into two parts, the outer segment and the inner. The outer segment is doubly refracting, contains the visual purple, and breaks up into many superposed discs when acted upon by certain reagents. The inner segment is spindle-shaped, granular, and singly refractive. The ellipsoid of Kraus is in the outer part of the inner segment, and exhibits a fibrous structure.

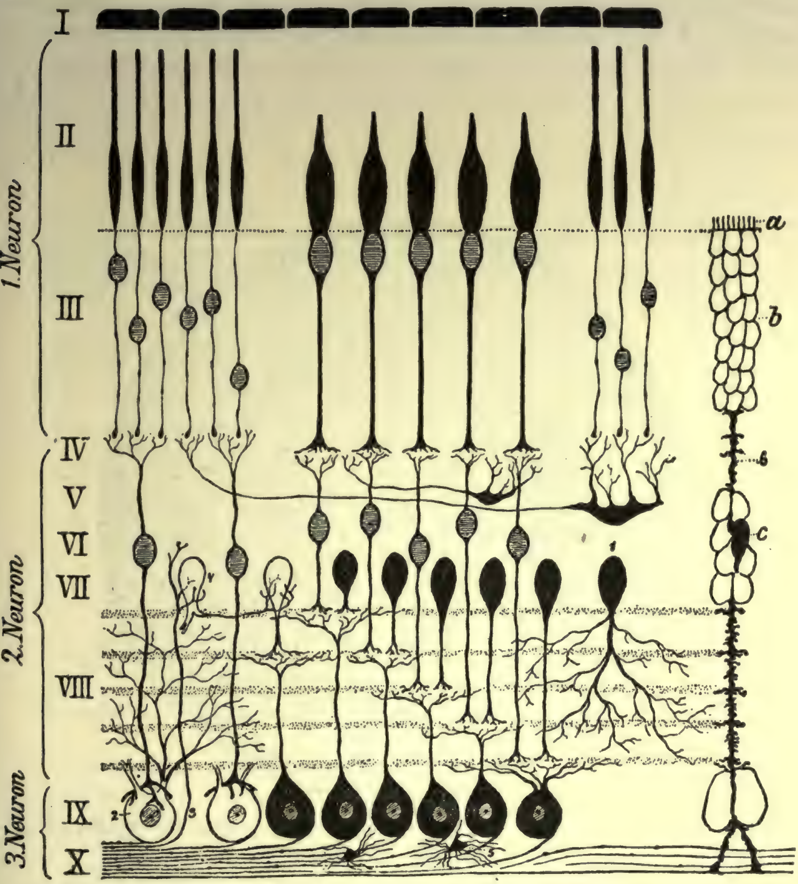


Fig. 334.—Diagram of the Structure of the Human Retina According to Golgi's Method. (Greeff.)

I, Pigment epithelium layer. II, Rods and cones. III, Granules of the visual cells. IV, Outer plexiform layer. V, Layer of horizontal cells. VI, Layer of bipolar cells. VII, Layer of amakrine cells. VIII, Inner plexiform layer. IX, Ganglion cell layer. X, Layer of nerve fiber. 1, Diffuse amakrine cell. 2, Diffuse ganglion cell. 3, Centrifugal nerve fiber. 4, Amakrine association fiber. 5, Neuroglia cells. 6, Müller's radial fibers.

The rod-fiber is a continuation at its inner end of the rod. The fiber contains the rod-nucleus.

Cones.—Both rods and cones are closely set like a palisade over the whole extent of the retina, between the external limiting membrane and the pigmentary layer, except at the macula lutea, where there are only cones. The smallest angular distance at which points can be separately distinguished is 50 seconds, with which the size of a retinal image is 3.65 micromillimeters. This size coincides closely with the diameter of the cones at the fovea, which are about 3 micromillimeters.

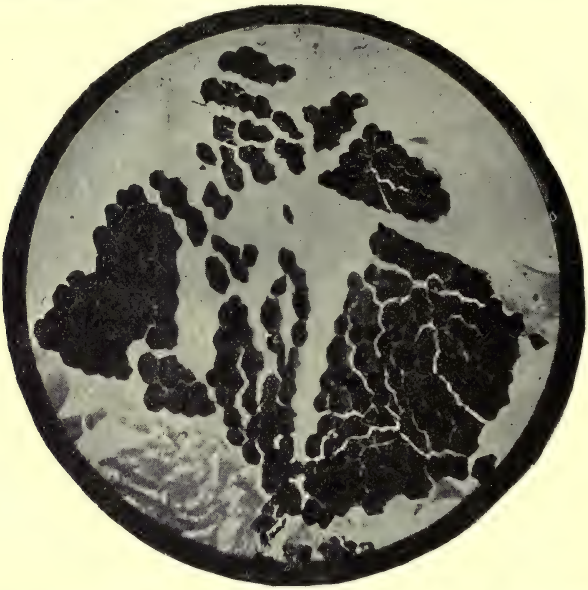


Fig. 335.—Hexagonal Cells from the Pigment Layer of the Retina of a Rabbit. (Ball.)

The cones, like the rods, consist of two segments, an inner and an outer. The cones are shorter than the rods. The outer segment of the cone has cross striations. The inner segment is much thicker and shorter than the rod, and is rounded. The ellipsoid of the cone is larger than that of the rod, and lies in the peripheral part of the inner segment. A cone-fiber is a continuation of the cone. Between each cone there are usually two or three rods, showing the greater abundance of rods. The external limiting membrane is a product of the Müller fibers, the sustentacular tissue of the retina. In the vicinity of the ora serrata the nerve-fiber and ganglion-cell first disappear. At a certain distance from the ora serrata the rods disappear, and then the cone-cells change and become a layer of cylindrical epithelium.

The Pigmentary Layer.—It is composed of hexagonal pigment-cells. The outer surface of the cell, turned towards the choroid, is smooth and flattened, and the part of the cell near this surface is without pigment and is nucleated. The inner boundary of the cell is loaded with pigment and is prolonged into fine, straight, filamentous processes, which reach for a certain distance into the outer segments of the rods and cones, which are imbedded in the pigment-cells. The pigment is in the form of small, dark-brown granules and rods. In the dark, the pigment is mainly heaped up in the body of the cell; but when light strikes the pigment, it is drawn in between the rods. The pigment seems to renew the visual purple of the outer segment of the rods after they have been bleached by the light. The eyes of albinos have no pigment in the cells.

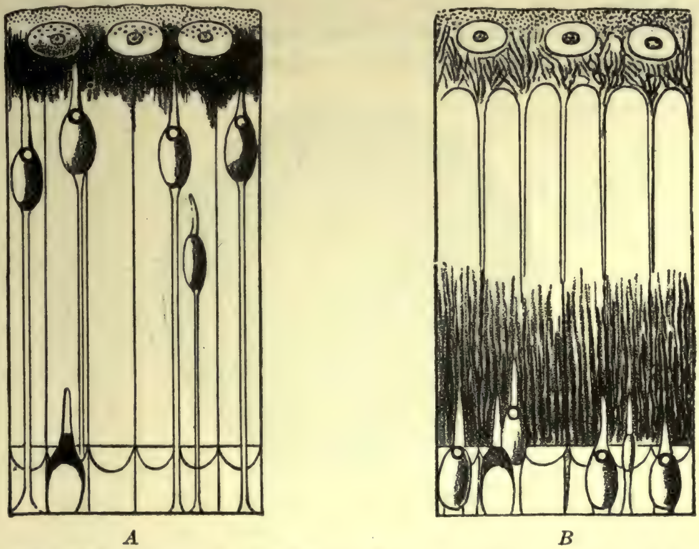


Fig. 336.—Action of the Light on Retina. Section of retina of frog. (Englemann.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

A, After two days of rest, animal in dark, pigment concentrated, cones protruded. *B*, After diffuse daylight, cones retracted, pigment diffused.

Macula Lutea.—The yellow spot of Soemmering is an oval depression in the center of the retina. It measures one-twentieth of an inch across and is one-tenth of an inch to the outer side of the point of entrance of the optic nerve. Its center is the *fovea centralis.* In the fovea there are *no rods;* cones only are present, and these are longer and narrower than those of the other parts of the retina.

When the optic nerve penetrates the eye it projects somewhat beyond the inner surface of the eyeball as a papilla. In this papilla there are none of the essential nerve-elements of the retina, so that rays of light cannot be perceived by this particular area; hence the name of *blind spot.*

The *nervous layer* of the retina is composed principally of the terminal nerve-elements of the optic nerve. Externally, it is coated with a pigment-layer; internally, it is lined with a homogeneous, transparent structure, the *hyaloid membrane.*

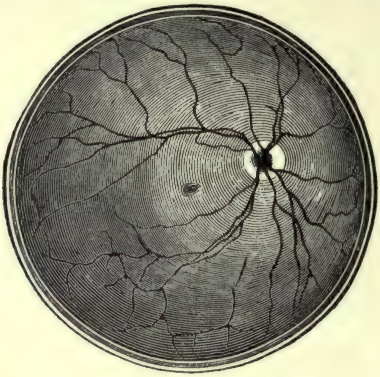


Fig. 337.—Right Eye, Normal Fundus Oculi. (Ball.)

Histological Structure.—The histological structure of the retina is very complicated. The retina is really an outward expansion of the original forebrain. The retina is usually divided into eight layers:—

1. The layer of nerve-fibers.
2. The layer of ganglionic cells.
3. The inner molecular layer.
4. The inner nuclear layer.
5. The outer molecular layer.
6. The outer nuclear layer.
7. The layer of rods and cones.
8. The hexagonal pigment-layer.

The first layer consists of neuraxons from the ganglionic cells of the second layer. The second layer consists of a lot of multipolar nerve-cells, and their neuraxons run inward to form most of the fibers of the optic nerve. The dendrons of these multipolar cells are branched and terminate in the inner molecular layer, of which this third layer is chiefly composed. The fourth inner nuclear layer is made up chiefly of round and oval cells with a peripheral neuraxon and a central neuraxon.

The peripheral neuraxon arborizes around the dendrons of a ganglionic cell in the inner molecular layer.

The fifth outer molecular layer is made up of the arborizations of the neuraxons of the visual cells of the outer nuclear layer.

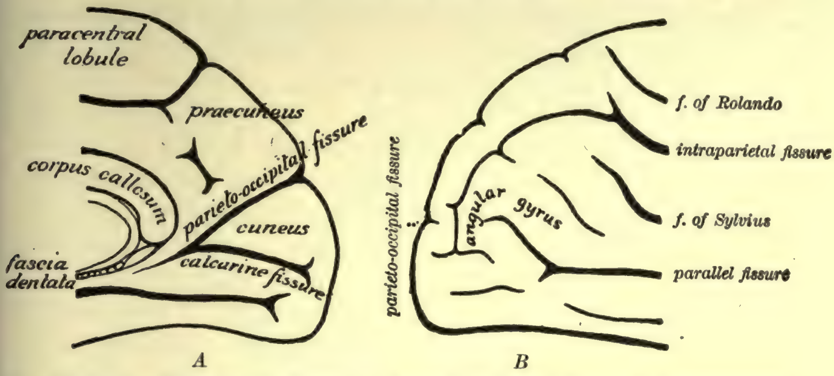

paracentral lobule
praecuneus
parieto-occipital fissure
corpus callosum
cuneus
fascia dentata
calcarine fissure
A
parieto-occipital fissure
f. of Rolando
intraparietal fissure
angular gyrus
f. of Sylvius
parallel fissure
B

Fig. 338.—Diagram of Occipital Region of Right Cerebral Hemispheres. (Ball.)

A, From inner, and *B*, from outer aspect.

The sixth layer, the outer nuclear layer, is the layer of bipolar visual cells. Their central neuraxons end in arborizations in the outer molecular layer about the dendrons of the bipolar cells of the inner nuclear layer. The peripheral processes of these cells are the rods and cones of the retina, which are similar to the dendrons of other nerve-cells.

The seventh layer of rods and cones are the dendrons of the visual cells.

The eighth layer is the pigment-layer of the retina.

The retina is essentially formed by a number of nerve-cell chains, the elements of which are arranged in three series from without in. The first is the rod and the cone; the second is the bipolar cell, which interlaces with the peripheral dendrons of the ganglonic cells. The third element is the ganglion-cell.

The optic tract arises in the retinal cells, which are its trophic center. These retinal cells send in fibers which arborize around the cells of the anterior corpora quadrigemina, pulvinar, and the lateral corpus geniculatum. Now, from the lateral corpus geniculatum and pulvinar we have a second set of neuraxons running to the occipital cortex, the center of vision. Here the lateral corpus geniculatum and pulvinar are the relay centers in the path of visual impulses.

THE VITREOUS HUMOR.—The hyaloid membrane, a homogeneous capsule, encloses the vitreous humor. This hyaloid membrane divides as it comes forward over the vitreous, one part going to the capsule of the lens as the zonule of Zinn, and the other passing in front of the vitreous. The free part of the hyaloid, stretching from the capsule of the lens to the ciliary body, is termed the suspensory ligament of the lens. Between these two layers of the hyaloid the canal of Petit is formed, a lymphatic canal. In the center of the vitreous is the canal of Stilling, which, in the fœtal state, was the pathway of the artery of Zinn to the posterior part of the capsule of the lens. The vitreous has no blood-vessels, and is composed chemically of water, 98.5 per cent., and salts, extractives, and traces of proteid and nucleo-albumin. The vitreous has fine intercrossing connective-tissue fibers, connective-tissue cells, and leucocytes.

AQUEOUS HUMOR.—This fluid contains about 2 per cent. of solids, chiefly in the form of sodium chloride. It occupies the anterior chamber in the space back of the cornea and in front of the iris. The so-called posterior chamber lies between the back of the iris and in front of the lens.

When by ulceration of the cornea or accident the aqueous humor escapes, it is found to be regenerated very rapidly.

The *secretion* of the aqueous humor has been studied by fluorescin instilled into the fluids of the eyeball. It has been found that the humor is secreted by the posterior surface of the iris and ciliary body. It passes through the pupil into the anterior chamber.

BLOOD-VESSELS OF THE EYE.—There are two systems of blood-vessels: the retinal and the ciliary system. These systems are separate, and anastomose only at the place of entrance. The retinal system is the central artery of the retina, which goes through the axis of the optic nerve until it reaches the optic papilla, where it divides into two branches, one running forward and the other in a posterior direction. These vessels are seen with the ophthalmoscope.

The Ciliary System.—These break through the sclera to supply the choroid, the ciliary body, and the iris.

The short ciliary, about six to twelve in number, supply the choroid and ciliary processes.

The long ciliary, two in number, penetrate the sclerotic, run forward between the choroid and sclerotic to the ciliary muscle, forming a very vascular circle about the iris.

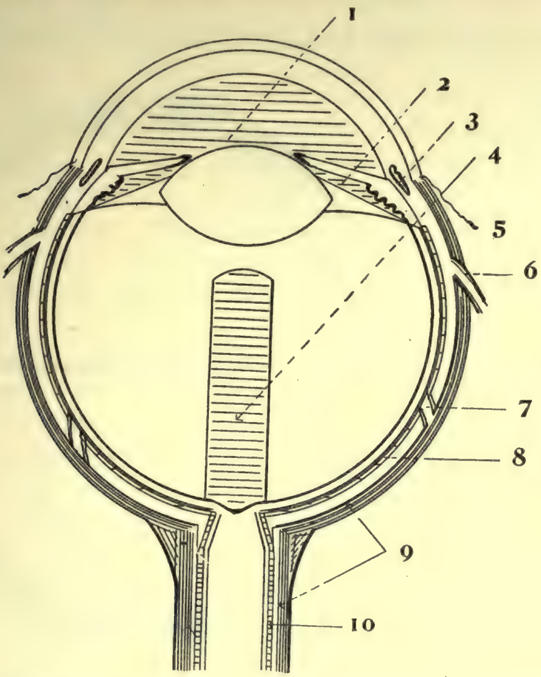


Fig. 339.—Diagram of the Lymph Spaces of the Eyeball. (After FUCHS.)

1, Anterior chamber. 2, Posterior chamber. 3, Canal of Schlemm. 4, Hyaloid canal. 5, Anterior ciliary vein. 6, Continuation of Tenon's capsule on the ocular tendons. 7, Lymph space around the vena vorticosa. 8, Perichoroidal space. 9, Supra-vaginal space. 10, Inter-vaginal space.

In deep-seated ciliary congestion you have a pus-zone about the cornea, which is much different from the bloodshot eye of conjunctivitis.

The capsule of Tenon is a thin membrane which envelops the eyeball from the optic nerve to the ciliary region, forming a socket in which it plays. On its inner surface it is smooth, and is in contact with the outer surface of the sclerotic, the perisclerotic lymph-space lying between it and the sclerotic. There are some unstriped muscular fibers in the capsule of Tenon. These muscular fibers are innervated by the cervical sympathetic, and project the eyeball when in action.

Intraocular Pressure.—The intraocular pressure depends upon the tension of blood in the arteries of the eye. The pressure undergoes oscillations simultaneous with the pulse and respiratory movements.

The pressure is about 20 to 30 millimeters of mercury.

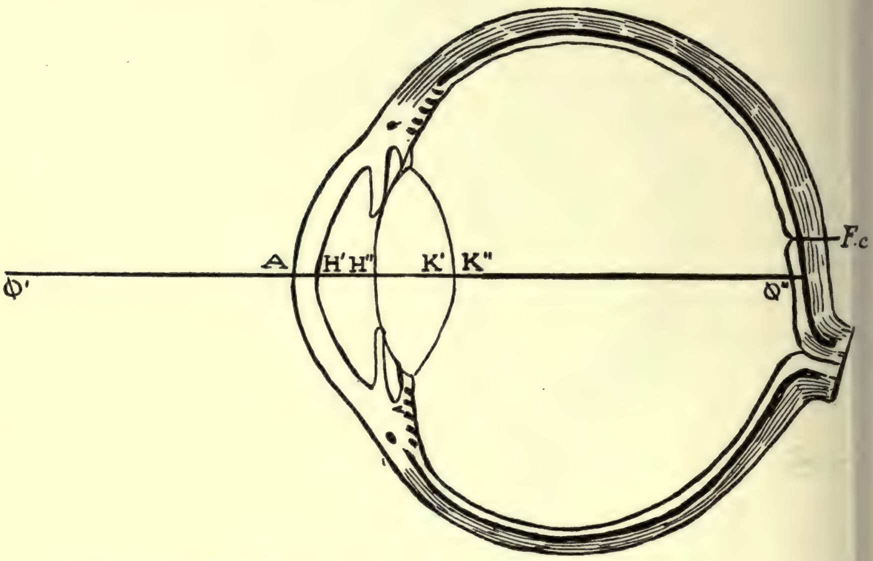


Fig. 340.—Schematic Eye three Times Natural Size. (LANDOLT.)

ϕ', Anterior or principal focus. *A*, Anterior surface of cornea. *H'* and *H"*, Principal points. *K'* and *K"*, Nodal points. ϕ'', Posterior or second principal focus. *F.c*, Fovea centralis. ϕ', ϕ'', Optic axis.

The aqueous humor, which is secreted and absorbed with great ease, appears to regulate the pressure.

LYMPHATICS.—The lymphatics of the eye comprise an *anterior* and *posterior set.* The former is located in the anterior and posterior chambers of the eye and has communication with the lymphatics of the iris, ciliary processes, cornea, and conjunctiva. The posterior set consists of the perichoroidal spaces lying between the choroid and sclerotic coats of the eyeball.

Optic Nerve.

The optic nerve contains centripetal and centrifugal fibers. The bundle of centripetal fibers from the second layer of retinal ganglionic cells, which originate in the vicinity of the macula, go into the optic tract of the same and opposite side. Those going into the optic tract of the same side come from the temporal tract of the macula, while the decussating fibers come from the nasal side of the macula; hence each optic tract is made up of fibers from the temporal half of the retina of the same eye and from the nasal half of the opposite eye. The optic tract then goes backward, passing around the cerebral peduncle, and breaks up into two bundles, the external and the internal. The internal bundle is connected with the internal geniculate body and the posterior corpus quadrigeminum, and is a part of Gudden's commissure. It has no connection with vision. The external bundle goes to the external geniculate body, the pulvinar and anterior corpus quadrigeminum. The cells in the external geniculate body receive the terminal arborizations, as also do the cells of the pulvinar and corpus quadrigeminum. From these ganglia neuraxons go through the most posterior end of the internal capsule (optic radiations of Gratiolet), to end in the occipital lobe, mainly in the cuneus.

The pyramidal cells send centrifugal fibers to the external geniculate body, to the pulvinar and the anterior corpus quadrigeminum, and from here new centrifugal axons go to the retina.

Irritation of the occipital cortex in the monkey, say of the right lobe, causes movement of the eyes to the opposite side, through the action of the efferent fibers.

The average dimensions of the dioptric system of the eye are as follows:—

Index of refraction of air	1.	
Index of refraction of cornea, aqueous humor, and vitreous body	1.3365	
Total index of refraction of the crystalline lens	1.4371	
Radius of curvature of the cornea	7.829	mm.
Radius of curvature of the anterior surface of the crystalline lens	10.0	mm.
Radius of curvature ot the posterior surface of the crystalline lens	6.0	mm.
Distance from the apex of the cornea to the anterior surface of the crystalline lens	3.6	mm.
Distance from the apex of the cornea to the posterior surface of the crystalline lens	7.2	mm.
Thickness of the lens	3.6	mm,

Using the above values, the positions of the cardinal points of Gauss, of the human eye on the optical axis, calculated from the apex of the cornea, are as follows:—

The first principal focus is situated 13.745 millimeters in front of the cornea.

The other points are behind the cornea:—

The first principal point	**1.7532 mm.**
The second principal point	**2.1101 mm.**
The difference is	**0.3569 mm.**
The first nodal point	**6.9685 mm.**
The second nodal point	**7.3254 mm.**
The second principal focus	**2.28237 mm.**

These values are shown in Fig. 340, but are three times as great as in nature.

From these data are shown the course of rays through the eye and the position and size of images.

Perception of Light.

Light is due to vibrations of ether; a proper conception of them gives the sensation of sight. Transmission of light, with air as a medium, is 186,000 miles per second. The rapidity of the vibrations influences the sensation produced, for color is for luminous sensation what height is for sound. The inferior limit of visible vibrations is represented by the color red; the superior limit is exemplified in violet.

For light to be perceived physiologically by any individual it must make an impression upon the retina. The light falling upon the retina immediately stirs up certain changes in it which in turn give rise to nervous changes in the fibers of the optic nerve. This last change, or "visual impulse," produces a further series of events within the brain, one effect of which is a change in our consciousness; that is, there is a sensation.

The point upon the retina at which the impressions are strongest and most exact is the macula lutea and its fovea centralis. The anatomical layer designed to be impinged upon by a distinct image is the membrane of Jacobson, the layer of rods and cones. As only the cones, and no rods, are found in the fovea centralis, it is the point where objects are fixed. Hence it must be held that the cones are the specific elements of the retina that are designed to make the individual perceive a luminous impression precisely. Nevertheless, the field of vision, though indistinct toward its periphery, is very much enlarged.

The luminous impression consists of the vibrations of the luminous ether which stimulate the outer portion of the rods and cones. In them there is produced a molecular, mechanical change, or disturbance. Whenever the layer of rods and cones is stimulated, the excitation is propagated from without inward to all of the retinal elements.

Von Kries holds that the cones alone have the power to perceive colors (day vision), whilst the rods are sensitive only to light and darkness. The rods, by their adaptability in the dark through the regeneration of their visual purple, form the special apparatus for vision in dim lights (night vision). The various elements are connected by fibers, and, finally, by the optic nerve with the brain.

Physiology of the Eye.

The study of the phenomena of the eye may be divided into four parts: (1) *dioptrics,* (2) *accommodation,* (3) *imperfections* and *corrections,* and (4) *vision with both eyes.*

Dioptrics.—The eye has previously been mentioned as being like a camera obscura. If a small opening exist in the shutter of a dark room the rays of light from the outside passing through the opening will form an inverted image of the external object upon the opposite wall of the chamber. However, unless the opening be very small, the image will be blurred and indistinct. These latter qualities will be due to overlapping of rays of light from various points of the object. If the opening be small enough the overlapping rays will be cut off and a distinct image be formed. Should a convex lens be interposed in the path of the rays of light the opening may be very considerably enlarged, and yet the various rays be brought to a focus so that diffused images will be prevented.

The camera obscura is popularly known to-day in the form of the photographic camera. The latter consists of a box blackened on the interior to prevent reflection from the walls. In front is a short tube which contains achromatic lenses. In the back wall of the camera is found a ground-glass plate upon which the image formed by the lens is focused. If the camera be so adapted that parallel rays falling upon the lens are focused upon the ground-glass plate, then divergent rays must have their focal point behind the plate. Should the plate be moved backward or forward the focal point can be made to coincide with the conjugate focus of the rays diverging from the object.

Spherical Aberration, which interferes with distinctness, is gotten rid of by cutting off outside rays. In the camera this point is accomplished by the insertion of a diaphragm through a slit in the lens-tube. The diaphragm is pierced by holes—a larger or smaller one being used according as the light is feeble or strong.

The eye may be very aptly compared to the camera. It has a small opening in front through which pass the rays of light. The sclerotic and choroid coats form its walls. The refracting lenses are the cornea, aqueous humor, crystalline lens, and vitreous humor. They all tend toward the accomplishment of the same end: to bring parallel rays of light to a focus upon a sensitive plate (the retina), there to form a real inverted image of the object. Last, the iris with its pupil acts as a diaphragm.

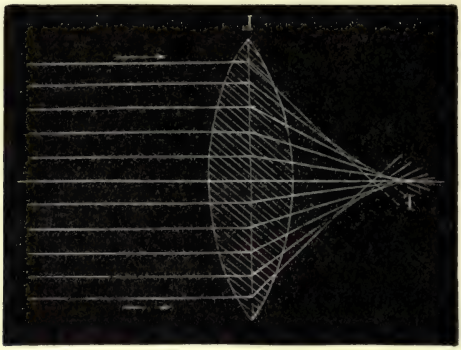


Fig. 341.—Diagram Illustrating Spherical Aberrations. (Ganot.)

The rays passing through the edge of the lens have a shorter focal distance than those passing nearer to the center.

Chromatic Aberration.—The edge of the lens of a camera represents the outer angle of a prism. White light falling upon it is decomposed into its spectral components. Objects seen upon the ground-glass plate have an iridescent hue. In the eye this trouble is obviated by the presence of the iris and the fact of the edge of the lens being more angular and less curved.

Visual Angle.—It is usually stated to be the angle included by the lines from the extreme points of the object where they cross at the nodal point. The apparent size of the object depends upon the visual angle. Acuteness of vision is inversely as the size of the visual angle.

Act of Accommodation.—When a luminous body is brought too near to the eye, the rays which pass from it tend to come to a focus behind the retina. In this way circles of diffusion form, which would prevent the appearance of a distinct image if a special apparatus did not exist for the purpose of modifying the degree of refraction. This modification is what is understood by the term accommodation.

Mechanism of Accommodation.—The ciliary muscle, when it contracts, causes the zone of Zinn to advance, and thus diminishes the tension exercised by the latter upon the capsule of the crystalline lens. The lens, left to itself, assumes the form which the elasticity of its fibers naturally gives it and becomes more convex, especially at its anterior surface. When the action of the oculomotor nerve ceases, the ciliary muscle is relaxed, the ciliary processes become tense and make traction on the zone of Zinn, which in turn flattens the lens by exerting upon it a traction in the direction of its equator. The retina follows along with the choroid in the movement of accommodation. When the traction of the ciliary muscle ceases relaxation of accommodation in this way, the border of the retina, being closely attached with the choroid, is stretched and irritated by the sudden relaxation of accommodation until the lens flattens.

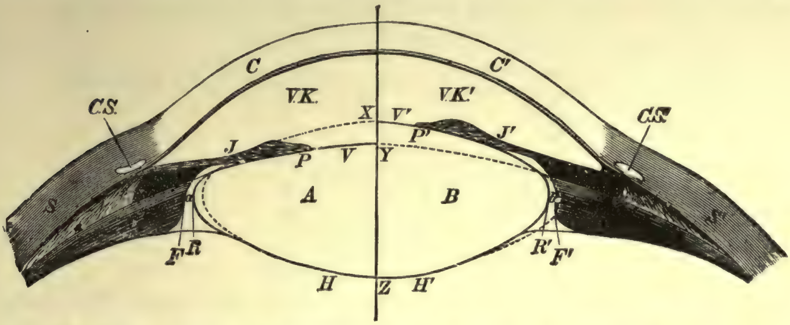


Fig. 342.—Scheme of Accommodation for Near and Distant Objects. (Landois, after Helmholtz.)

The right side of the figure represents the condition of the lens during accommodation for a near object and the left side when at rest. The letters indicate the same parts on both sides; those on the right side are marked with a stroke (or minute mark). *A*, Left half of lens. *B*, Right half of lens. *C*, Cornea. *S*, Sclerotic. *CS*, Canal of Schlemm. *VK*, Anterior chamber. *J*, Iris. *P*, Margin of pupil. *V*, Anterior surface. *H*, Posterior surface of lens. *R*, Margin of the lens. *F*, Margin of ciliary processes. *a*, *b*, Space between the two former. The line *Z-X* indicates the thickness of the lens during accommodation for a near object. *Z-Y*, the thickness of the lens when the eye is passive.

These locomotor changes of the choroid may generate a choroiditis, especially in the production and progress of myopia. Atropine, by paralyzing the oculomotor nerve and thus the ciliary muscle, has a very favorable influence by putting the affected membranes at rest.

The suspensory ligament (zone of Zinn) is not a membrane, but an agglomeration of fibers of the nature of connective tissue. They originate partly at the ora serrata from the intervals between the ciliary processes, and a few of them from the ciliary processes themselves.

Accompanying the act of accommodation is a contraction of the pupil, which dilates when the accommodation relaxes, and a convergence of the eyeballs due to a contraction of the internal recti.

The range of accommodation is as follows:—

Years	Range of Accommodation	Years	Range of Accommodation
10	14 D.	45	3.5
15	12	50	2.5
20	10	55	1.75
25	8.5	60	1.
30	7	65	0.75
35	5.5	70	0.25
40	4.5	75	0.

This table shows that the power to accommodate diminishes rapidly and considerably as we become older. This is due to the decreasing elasticity of the crystalline lens. The crystalline lens commences early to change its physical constitution and becomes more rigid, whilst our other bodily forces are in a state of progressive development.

In what may be regarded as the normal, or so-called emmetropic, eye, the near point of accommodation is about *five* inches. The far limit, for all practical purposes, is from 200 feet up to an infinite distance. In this eye the range of distinct vision has wide latitudes.

In the *myopic*, or short-sighted, eye the near point is two and one-half inches from the cornea. The far limit is at a variable, but not very great, distance. The range of vision in this eye is very limited. In this the rays of light are brought to a focus in front of the retina.

In the *hypermetropic*, or far-sighted, eye rays of light coming from an infinite distance are, in the passive state of the eye, brought to a focus behind the retina. The near point is some distance away.

The *presbyopic*, or long-sighted, eye of aged persons resembles the hypermetropic eye, but differs in so far that the former is an essentially defective condition of the mechanism of accommodation.

There are two changes which occur when we accommodate for near objects: one is that the pupil contracts to cut off divergent rays; the other is a change of curvature of the lens. The ciliary muscle is the motive power of accommodation. Its paralysis renders accommodation impossible. The oculomotor innervates the ciliary muscle. Its paralysis by atropine produces both dilatation of the pupil and inability to accommodate.

To correct anomalies of refraction it is necessary to use lenses. These are transparent media which seem to refract rays of light passing through them. They have curved surfaces. The direction which the rays take on emerging from the medium depends upon the nature of the curvature. The chief forms of lenses are *convex* and *concave;* convex lenses may be doubly convex, plano-convex, or concavo-convex. A concave lens may have equivalent features. A convex lens converges the rays of light; a concave lens diverges the rays of light. In myopia a concave lens is used; in hypermetropia and presbyopia, a convex lens.

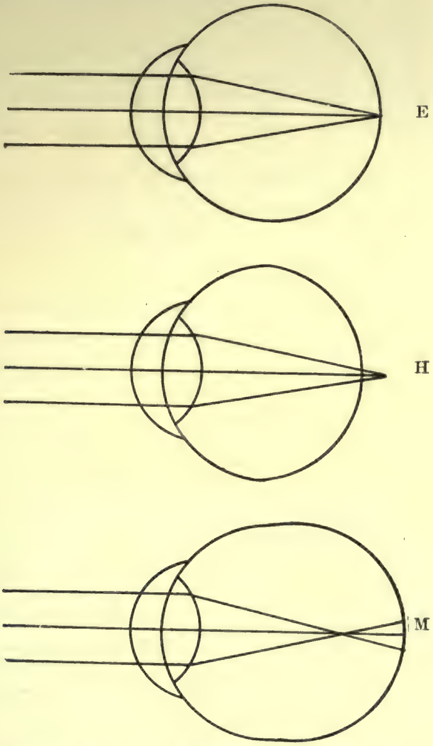


Fig. 343.—Refraction of Parallel Rays of Light in Emmetropia (*E*), Hypermetropia (*H*), and Myopia (*M*). (BALL.)

Astigmatism is a defect of refraction due to a want of symmetry in the refracting media of the eye. The result of this is that the rays of light passing through the lens are not brought to a focus at the same point. This want of symmetry is usually in the cornea, but may be in the lens. To remedy this defect we use a lens called a cylinder to level up the curvature of one of the meridians of the cornea to correspond to the curvature of the others. Cylinders have no curvature in one axis, but more or less considerable curvature in the opposite axis in correspondence with the degree of astigmatism that has to be corrected.

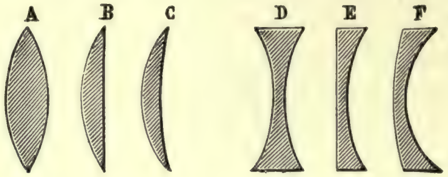


Fig. 344.—Different Kinds of Lenses. (GANOT.)

A, Double convex. *B*, Plano-convex. *C*, Converging concavo-convex. *D*, Double concave. *E*, Plano-concave. *F*, Diverging concavo-convex. *C* and *F* are also called meniscus lenses.

LENSES.—Lenses are arranged according to their focal distance in inches, and, as the unit was taken as one inch, all weaker lenses were expressed in fractions of an inch. However, Donders made the standard in lenses of a focal distance of one meter, and this unit he called a dioptre. Thus the standard in a weak lens and the stronger lens are multiples of these. Hence a lens of two dioptres equals one of about twenty inches' focus.

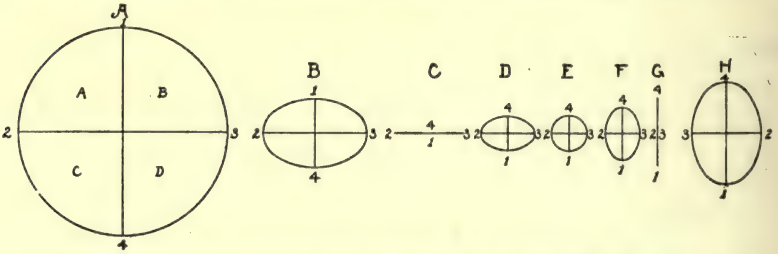


Fig. 345.—Refraction of Rays in Regular Astigmatism. (BALL.)

PURKINJE-SANSON'S IMAGES.—If you place a lighted candle in front of the eye of a person, three images of the flame are seen. One, which is direct, small, brilliant, and comes from the anterior surface of the cornea; another, which is in the middle, is direct, larger, but not so bright, and is due to the anterior surface of the lens, which acts as a convex mirror; and, finally, a third image, small, inverted, and brilliant, due to the posterior surface of the lens, which also acts as a convex mirror. If the person experimented on looks fixedly at objects placed at different distances, the only change in the three reflections which we mentioned will be found to take place in that caused by the anterior surface of the crystalline lens. This fact leads to the conclusion that the phenomena of accommodation are dependent upon a change in the anterior surface of the crystalline lens.

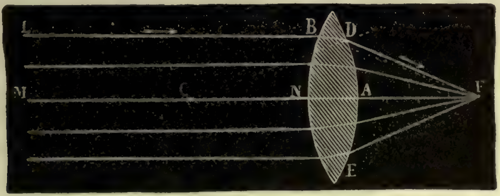


Fig. 346.—Diagram Showing Refraction by a Double Convex Lens. (GANOT.)

The incident ray (*L-B*) is refracted at the points of incidence (*B*), and emergence (*D*), toward the axis (*M-N-A*), which it cuts at *F*.

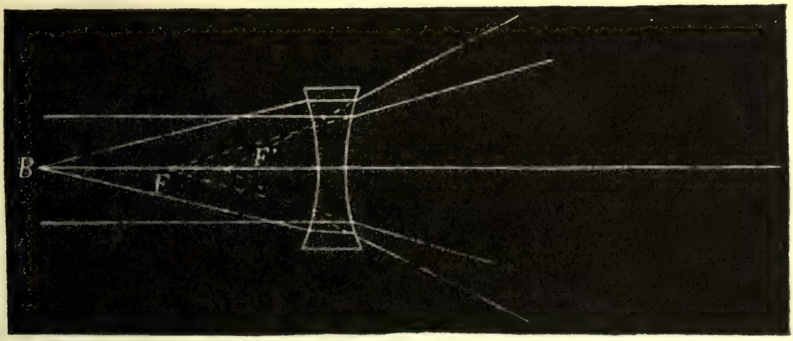


Fig. 347.—Concave Lens Diverging Parallel Rays of Light. (LAHOUSSE.)

In the act of accommodation, when the candle is brought nearer the eye, the image due to the anterior surface of the crystalline lens becomes smaller because the lens becomes more convex.

The form and variations in form of the dioptric surfaces of the eye can be measured by Helmholtz's ophthalmometer and the phakoscope of Helmholtz.

Blind Spot.—Marriotte's experiment proves that at the entrance of the optic nerve, where rods and cones are not to be found, the spot is a blind spot.

Thus: make a cross and a circle about three inches apart upon paper. With the right eye view the cross, keeping the left eye closed. Hold the paper about a foot from the eye, when both cross and circle will be visible. Let the paper be gradually brought nearer the eye, keeping the right eye steadily fixed on the cross. At a certain moment the circle will disappear, and that time is when the image of the circle falls upon the optic nerve entrance.

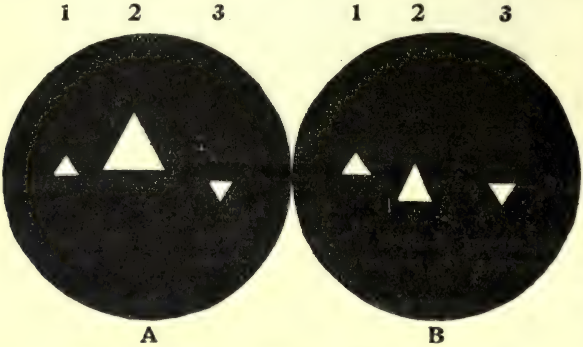


Fig. 348.—Purkinje-Sanson Images. (Ball.)

A, In the absence of accommodation. B, In accommodation. 1, Reflection from the cornea. 2, From the anterior surface of the lens. 3, From the posterior surface of the lens.

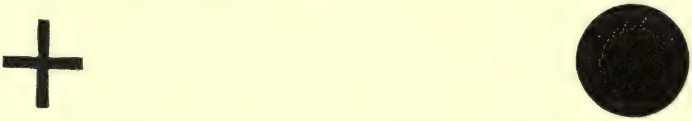


Fig. 349.—Diagram to Show the Blind Spot in the Visual Field. (Ball.)

The minimum visual angle is fifty seconds; below this limit the extreme points of an object are no longer separate and but one point is perceived. The minimum visual angle corresponds to a retinal image of about .004 millimeter, which is nearly the diameter of one of the cones of the retina.

Acuteness of Vision.—Acuteness of vision is in inverse ratio to the visual angle. It diminishes as the later increases. In favorable conditions, bodies having a diameter of $^1/_{40}$ to $^1/_{100}$ of an inch are perceived by the naked eye.

Circles of Diffusion.—When rays of light proceeding from a luminous object do not come to a focus directly on the retina, the image is no longer distinct, and circles of diffusion appear about it. In the normal condition, the luminous rays passing to a point of the retina through the pupil form a cone, the base of which is at the pupil and the apex at the retinal focus. But if the focus be placed in front of or behind the retina, the latter intersects the bundle of rays so that, instead of a point on the retina corresponding to one on the luminous object, we have a circle formed. The different points of the retina will be intersected by rays coming from various parts of the object, and the image in this way becomes blurred and loses its distinctness. The existence of these circles of diffusion explains why it is that we cannot at the same time see clearly objects which are placed at different distances from the eye. Their size varies with the distance of the focus from the retina, being larger as the distance is greater, and also with the size of the pupil, con-

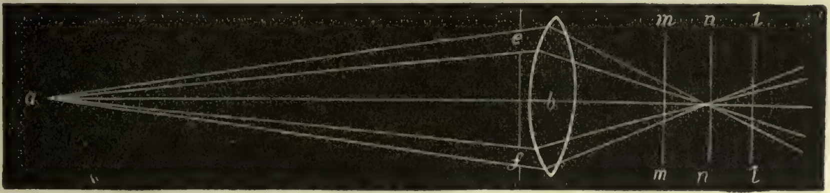


Fig. 350.—Scheiner's Experiment—an experiment to determine the minimum distance of distinct vision.

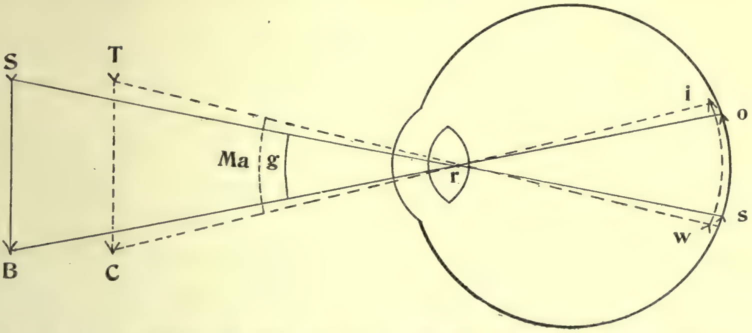


Fig. 351.—Diagram to show that the visual angle and size of the retinal image vary with the distance of the object from the eye. (Ball.)

The image of *S-B* is seen at *O.S.* under the angle *g*, and the image of *T.C.* is seen at *I-W* under the angle *Ma*.

traction of which narrows the cone of luminous rays and consequently the circles of diffusion.

Scheiner's Experiment.—A card is taken in which two small holes are placed close together. The card is held close to the eye, and in front of it a needle is held. When you move the needle nearer the card, and then farther from it, a position is found where it is distinctly seen. If it be brought slightly nearer, the needle appears double, and you obtain the double image. The explanation is easily seen from the diagram, Fig. 350.

e f represent the holes in the card, *a* the point of the needle, *b* a lens, and *m n l* a screen at varying distances from it. With the screen at *n*, a distinct single image of the needle is perceived, because the rays *e* and *f* coincide and are focused at *n n*. At the position *m* the image is blurred and double because the rays from *e* do not coincide with those from *f;* while at *l* the image is also double and blurred because the rays are intercepted after they have diverged from their focus. Let *b* represent the refractive media of the eye, and *m n* the retina.

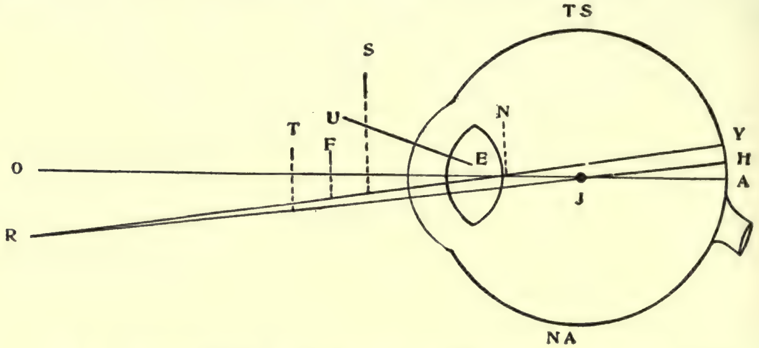


Fig. 352.—Diagram Showing the Corneal Axis, *U-E*; the Optic Axis, *O-A*; the Visual Line, *R-Y*; the Line of Fixation, *R-J*; and the Three Angles. (Ball.)

The angle between *U-E* and the visual line *R-Y* is the angle Alpha, averaging 5 degrees. The angle between the optic axis (*O-A*) and the line of regard (*R-J*) is the angle gamma. The angle between the optic axis (*O-A*) and the line of vision (*R-Y*) is the angle beta. *TS*, Temporal side. *NA*, Nasal side.

The Optic Axis.—This is a line which passes through the nodal point and the center of the cornea. If prolonged backwards, it falls upon the retina on the inner side of the yellow spot.

The Visual Line.—The visual line joins the macula lutea with the point on which the eye is fixed. It passes through the cornea a little to the inner side of its center, and therefore forms an angle with the optic axis, which is termed the angle alpha, which normally does not exceed 4 to 5 degrees.

Horopter.—The horopter represents all those points of the outer world from which rays of light passing into both eyes fall on identical points of the retina, the eyes being in a certain position.

It is a circle of which the chord is formed by the distance between the point of decussation of the rays of light in the eye. Its size is determined by the position of the two eyes and the point towards which their axes converge. All objects not found in the horopter, or which do not form an image on corresponding points of the retina, are seen double.

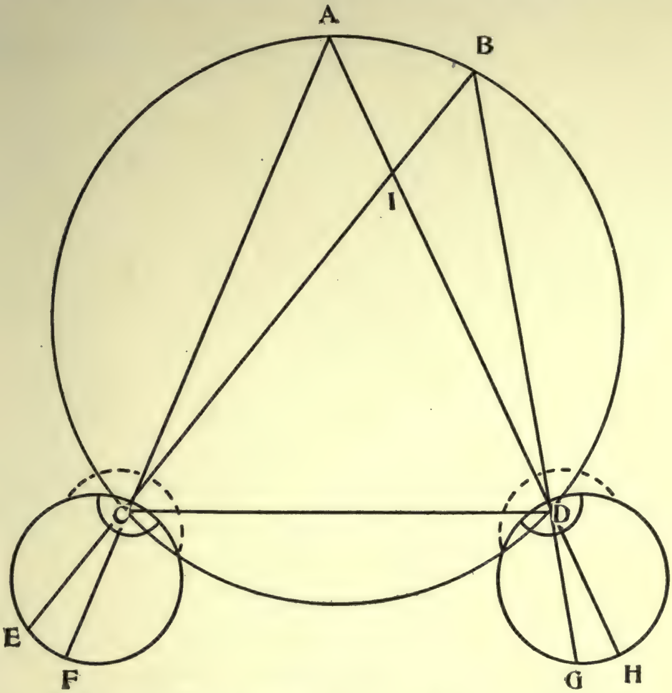


Fig. 353.—The Horopteric Circle of Müller. (Ball.)

Inverted Image of Objects.—The rays proceeding from the surface of luminous bodies above the optic axis cross in the eye so as to be brought to a focus below the axis, and *vice versa*. Thus an inverted image is formed on the retina.

The Acuteness of Vision is tested by Snellen's types. It has been found out that square letters which have limbs and parts equal in breadth to two of the height of the letters are distinctly legible to a normal eye under an angle of five minutes. These letters are numbered, the numbers expressing in meters the distance at which the letter can be seen under an angle of five minutes. The eye is tested with letters smaller and smaller at the same distance from the eye, 6 meters. Suppose No. 6 type is thus seen; then $^6/_6 = 1$, the acuteness of vision of a normal eye. If No. 8 is only seen at 6 meters, then the acuteness of vision is $^6/_8$ or three-fourths of that of the normal eye.

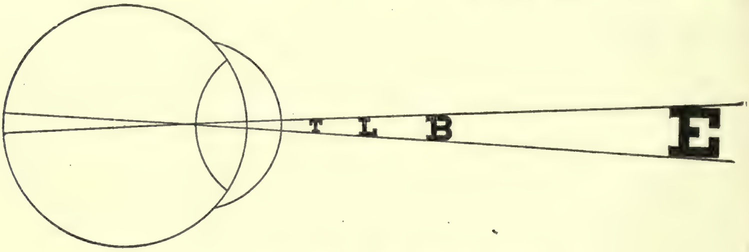


Fig. 354.—The Visual Angle.

Duration of Retinal Stimulation.—Light impresses the retina, but the excitation of it does not cease immediately with the disappearance of the luminous vibrations. Indeed, they persist for a certain time, about one-eighth of a second: that is, proportional to the intensity of the excitation. Upon a disc black and white sections are alternately painted. When the disc is made to rotate rapidly the disc appears neither black nor white, but gray.

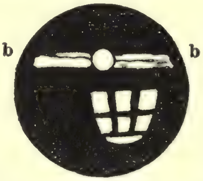


Fig. 355.—Optogram on the Rabbit's Retina of a Window Four Meters Distant. (Kühne.) (From Tigerstedt's "Human Physiology," copyright, 1906, by D. Appleton and Company.)

b, b, White streak of nerve-fibers, and yellow spot in its center.

Visual Purple, or Rhodopsin.—The outer part of the rods contains a reddish coloring matter which is called visual purple. The cones do not have any. This coloring matter must be kept in the dark, for it bleaches the moment light strikes it. But the color will return if the eye is again brought into a dark chamber. The bile acids extract the coloring matter from the retina. The visual purple is a product of melanin or fuscin.

Kühne has shown that an image or optogram of an object may be fixed on the retina by plunging it into a 4-per-cent. alum solution immediately after death.

The visual purple increases in the dark, and is supposed to render the rods more irritable in the dim light of the evening. Hence Van Kries has put forth the theory that the more abundant rods in the peripheral field of the retina are chiefly fitted for vision at night, whilst the cones are chiefly for day vision in strong light.

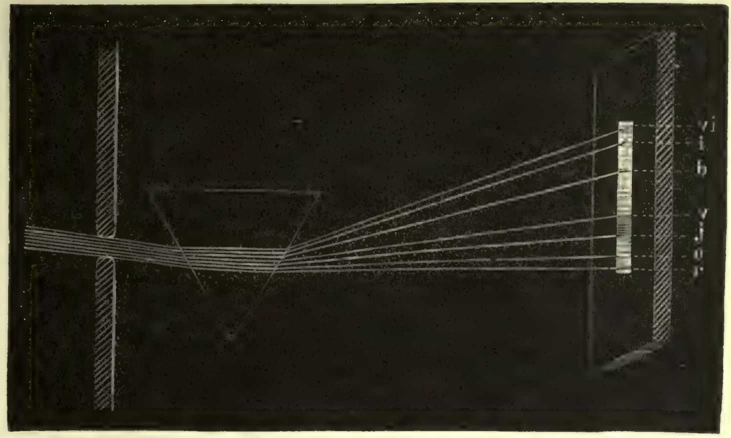


Fig. 356.—Diagram Illustrating the Decomposition of White Light into the Seven Colors of the Spectrum in Passing Through a Prism. (Beclard.)

***r*, Red. *o*, Orange. *j*, Yellow. *v*, Green. *b*, Blue. *i*, Indigo. *vi*, Violet.**

Color-vision.—White light is composed of rays of different refrangibility by reason of the different length and duration of the luminous rays. These various rays falling upon the retina determine in the individual different sensations which correspond to the colors. To decompose white light into its different colors, the prism is used. A ray of white light upon issuing from the prism presents the spectrum. That is, there emerge the principal simple colors from the most to the least refrangible. They are violet, indigo, blue, green, yellow, orange, and red. Each primary color cannot be further decomposed, but all can be reunited by a biconvex lens so that white light will result again. The ultra-red (thermal) and ultra-violet (chemical) rays do not make any impression upon the retina.

The former do not pass through the media of the eye, since by vibration-rates beneath 435,000,000,000 per second the retina is not stimulated; the latter color produces no sensation, since to vibration-rates above 764,000,000,000 per second the retina is insensible.

Sensations of Color.—In the production of the sensations of color there are three chief factors: *tone, saturation,* and *intensity.* The tone of the color depends upon the number of vibrations of the ether. A color is said to be saturated when it does not contain any white light. The simple colors of the spectrum are saturated. The intensity of color depends upon the amplitude of the vibrations.

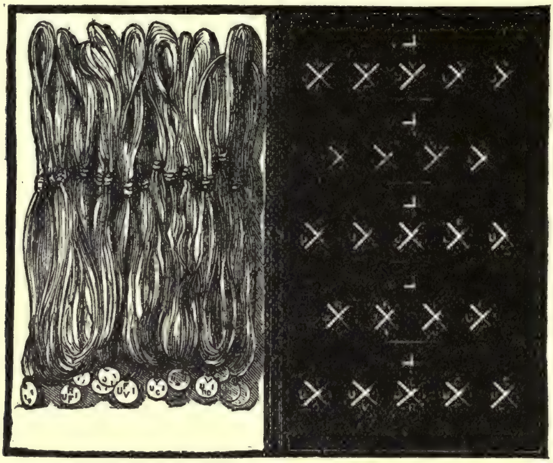


Fig. 357.—Wools for the Detection of Color Blindness. (Oliver.)

Loss of Color-vision, or Daltonism.—Young stated, as the explanation of color-vision, that all the colors were referable to three fundamental sensations: those of red, green, and violet. Corresponding to the three sensations excited by these three colors were three kinds of retinal fibers, stimulation of which gives rise to sensations of red, green, and violet. It is also supposed that white light stimulates these fibers with different degrees of activity according to the length of the wave. The longest wave acts most on the fibers which respond to the red color, the medium wave on the fibers which respond to green, and the shortest wave on the violet. Helmholtz adopted the theory of Young. It is also supported by the facts of color-blindness, in which there is an inability to distinguish one or more of the fundamental colors. The commonest form of color-blindness is that in which red is the invisible color, and in the compound colors in which red enters the complementary color alone is visible, white appearing as bluish green. Another theory of color-vision is that of Hering. The six sensations of color readily fall into three pairs, the members of each pair having similar relationship. White and black naturally go together, the one being antagonistic of the other. According to Hering, the retina is undergoing metabolic changes, and he supposes there are three distinct visual substances which are undergoing anabolism and catabolism. When breaking down, or catabolism, is in excess of the building up, or anabolism, we have a sensation of white; when upbuilding predominates, we have black.

Anabolism of the visual substances by the rays of light produces green, blue, and black; catabolism of these visual substances produces white, red, and yellow.

1. White is catabolic
and
Black is anabolic.

2. Red is catabolic
and
Green is anabolic.

3. Yellow is catabolic
and
Blue is anabolic.

In applying this theory to color-blindness it must be assumed that those who are red-blind want the red-green visual substance; they have only the black-white and yellow-blue visual substance in the retina.

According to the Young-Helmholtz theory, there is a defect corresponding to the three color-perceiving fibers. According to this theory color-blindness is of four kinds: red, green, and violet, and complete blindness to colors. In the Hering theory the kinds are: (1) complete, (2) blue-yellow, (3) red-green, and (4) incomplete color-blindness.

Color-blindness is also called Daltonism, after Dalton, a Quaker, who first described it. The percentage of color-blindness among persons is about 4 per cent. in males, and 1 per cent. in females; and among Quakers $4^{1}/_{2}$, because for generations they have worn drabs. The disease is hereditary. The cones in color-vision are, according to Van Kries, for the perception of color, whilst the rods are for the perception of light and darkness.

Complementary Colors.—Those colors are complementary which when mixed together produce white. The following table gives the complementary colors of the spectrum:—

Red—greenish blue.
Orange—Prussian blue.
Yellow—indigo-blue.
Greenish yellow—violet.
Green—purple.

Green alone has no complementary color in the spectrum. It gives a white color with the compound color purple.

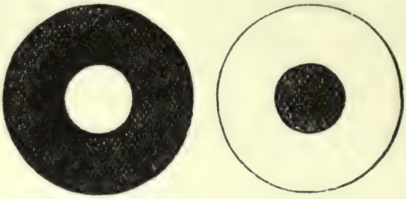


Fig. 358.—Diagram Illustrating Irradiation. (STIRLING.)

If this diagram is held some distance from the eye, especially if not exactly focused, the white dot will appear larger than the black, though both are of exactly the same size.

Irradiation.—This is a phenomenon which is observed when looking at a strongly illuminated object upon a dark background; the object appears larger than it really is. Thus, of two rings of equal size, one white on black, the other black on white, the former appears larger than the latter. Irradiation is due to imperfect accommodation. Here the margins of an object are projected upon the retina in circles of diffusion and the brain tends to increase the ill-defined margin to those parts of the visual image which are most prominent in the image itself. What is bright seems larger and overcomes what is dark. Black clothes make one appear to be much smaller than light clothes. A short person would look taller, and a fat person would look thinner, dressed in vertical stripes.

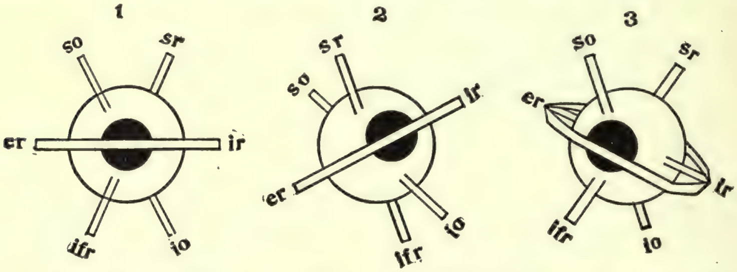


Fig. 359.—Diagram to show (1) the primary position of the right eye; (2) the eye turned upward and inward, and (3) downward and outward. (BALL.)

er, External rectus. *ir*, Internal rectus. *so*, *io*, Superior and inferior oblique. *sr*, *ifr*, Superior and inferior recti.

After-images.—When a bright light is thrown on the eye and then suddenly put out, there remains for a short time an impression of the same light, as though the retinal molecules still continued to vibrate from the light stimulus. This is a positive after-image. When the eye has received a stimulus for some time, the sensation which follows the withdrawal is of a different kind, and you have a negative after-image, which is due to exhaustion of the retinal cells. For instance, if you look at a red color for some time and the eye afterward is focused on a white ground, the negative after-image is a greenish-blue; that is, the color of the negative image is complementary to that of the object.

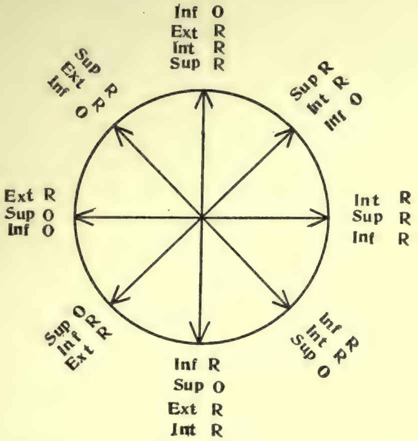
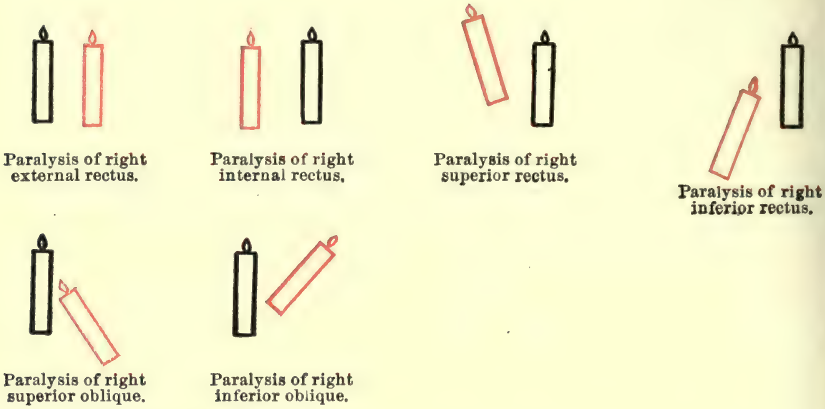


Fig. 360.—Muscles Associated in Moving the Eyeballs in the Directions Indicated by the Arrows. (Ball.)

Phosphenes.—If the retina be pricked, compressed, or twitched by any sudden movement, an impression of light will be produced. The same effect follows the use of electricity. Hence the retina is an essentially sensitive membrane. No matter by what cause its sensibility be excited, it always gives rise to the subjective phenomenon of a luminous sensation.

Vision with Both Eyes.—The study of phenomena bearing upon this subject comprises: (1) *movements* of the *eyes*, (2) *binocular vision*, and (3) the *advantages* of *sight with both eyes*.

Movements of the Eyes.—The eyeball may be considered as an articulated spherical globe which turns upon three axes that cross each other. Six voluntary muscles affect the three rotations of the eye. The rectus internus and externus, when acting alone, turn the eye from side to side. The superior and inferior recti give to the ocular sphere an up-and-down movement. The superior or inferior oblique muscle, acting alone, gives the eye an oblique movement.



Paralysis of right external rectus.

Paralysis of right internal rectus.

Paralysis of right superior rectus.

Paralysis of right inferior rectus.

Paralysis of right superior oblique.

Paralysis of right inferior oblique.

Fig. 361.—Positions of Images in Ocular Paralyses. (Ball.)

The true image is black, the false is red.

Coördinated Movements.—The two eyes always present coördinated movements in order to maintain the parallelism or convergence of the two visual lines. The visual line is that line which passes between the object, center of the pupil, and center of rotation of the ocular globe. For accommodation at a distance the two visual lines are parallel. In accommodation for near objects the lines are convergent.

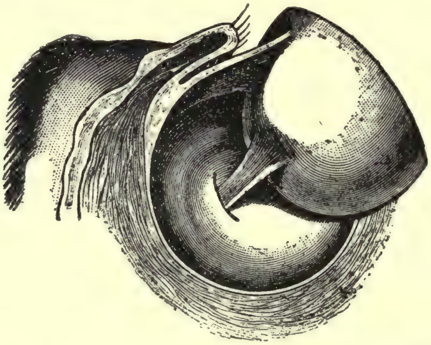


Fig. 362.—Capsule of Tenon. (Ball, after Merkel.)

So long as the muscles of the eyeball are normal in function their movements are in coördination. Should one or more become paralyzed or seized with spasm, then proper parallelism and convergence are lost. *Strabismus* will then be present and the object looked at will appear double: *diplopia.*

Stevens has given a number of terms for the deviation of the visual axis of nonparalytic origin. Thus orthophoria is a condition of muscular equilibrium of the eyeballs with the least nervous effort. Esophoria is a tending of the visual lines inwards. Exophoria is a tending of the visual lines outward. Hyperphoria is a tending of the visual lines of one eye in a direction above its fellow.

The innervation of the muscles of the eye is derived from the third, fourth, and sixth pairs of cranial nerves.

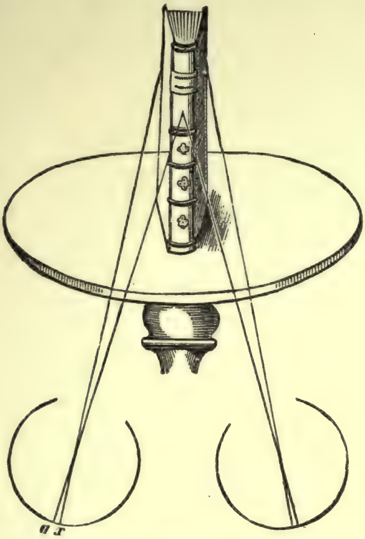


Fig. 363.—Diagram Illustrating Binocular Vision. (Beclard.)

The lines from the object indicate that rays from the back of the book fall on coincident points of the retina, while each eye further has a special field of vision.

Binocular Vision.—Looking into space with one eye, one sees an almost circular field. With the one eye he can look toward the opposite side as far as the root of the nose permits. If he opens the other eye the visual space becomes much more extended in a transverse direction, but corresponding to a monocular field, since the two monocular fields are superposed.

Why should any point or object be seen single and not double, when the point forms not one, but two images upon the retinæ? The explanation accepted is that the images are as two corresponding identical points. These points are so related to one another that the sensations from each are blended into one perception. The movements of the eyeballs are also adapted to bring the image of the object to fall upon identical parts. The law results that if one luminous point simultaneously impresses two identical points, it must be seen as single and not double. The two images are referred to one point in space and they produce in the individual only one impression.

The muscles concerned in the movements of the eyeball are as follows:—

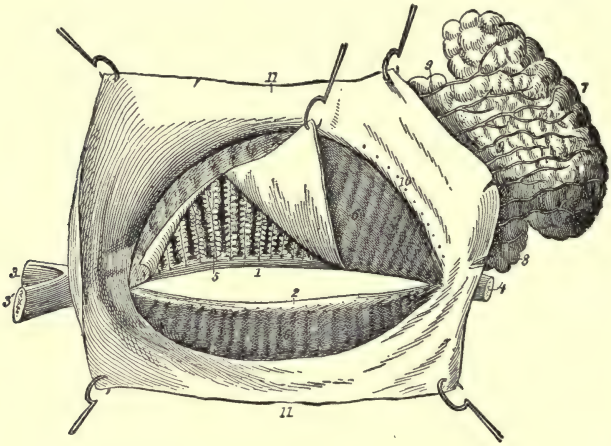


Fig. 364.—Lacrimal and Meibomian Glands, the latter viewed from the posterior surface of the eyelids. The conjunctiva of the upper lid has been partially dissected off, and is raised so as to show the Meibomian glands beneath. (Raymond, after Testut.)

1, Free border of upper, and 2, free border of lower lid, with openings of the Meibomian glands. 5, Meibomian glands exposed, and 6, as seen through conjunctiva. 7, 8, Lacrimal gland. 9, Its excretory ducts, with 10, their openings in the conjunctival *cul-de-sac*. 11, Conjunctiva.

Inward—Rectus internus.

Outward—Rectus externus.

Upward—Rectus superior, obliquus inferior.

Downward—Rectus inferior, obliquus superior.

Inward and upward—Rectus internus, rectus superior, obliquus inferior.

Inward and downward—Rectus internus, rectus inferior, obliquus superior.

Outward and upward—Rectus externus, rectus superior, obliquus inferior.

Outward and downward—Rectus externus, rectus inferior, obliquus superior.

Stereoscopic Vision.—When two monocular pictures are placed side by side, and viewed by the two eyes respectively through the two halves of a convex lens, we have one form of the instrument called the stereoscope. The most striking results are produced by two photographs taken at the same time by two cameras, so placed that their axes shall form the same angle with each other as that which the axes of the two eyes would form when looking at the same object. When we look at a solid object near by with both eyes, the right eye sees farther round the object on the right side, and the left eye farther round on the left side. These two slightly different images, when compared in the mind, produce the perception of

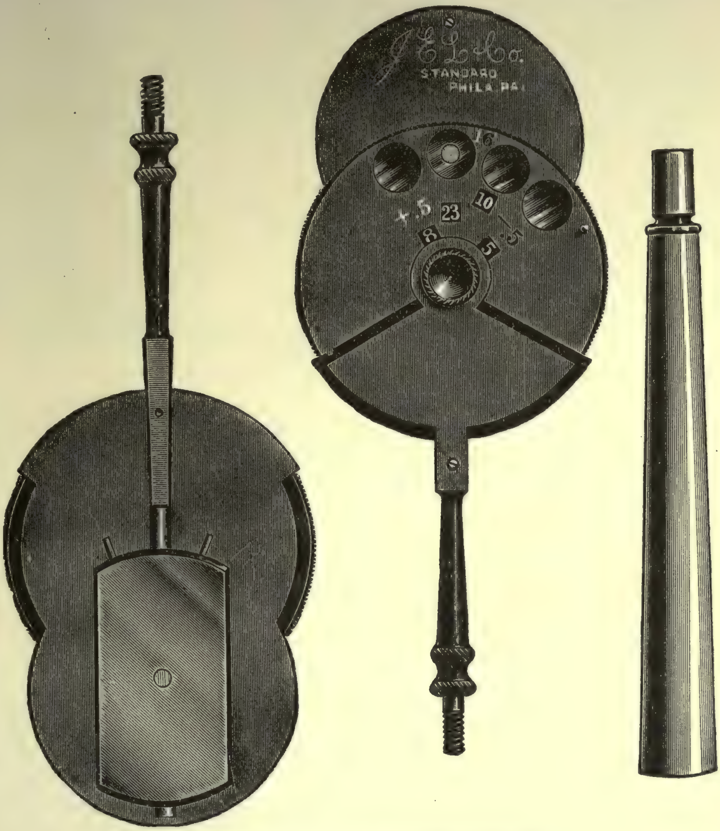


Fig. 365.—Loring's Ophthalmoscope.

solidity or depth, since experience has taught us that those objects only which have depth can affect the eyes in this way.

The photographs are slightly different from each other, for if they were identical no sensation of relief will ensue. The combination of the dissimilar images furnished by the two eyes is a mental act.

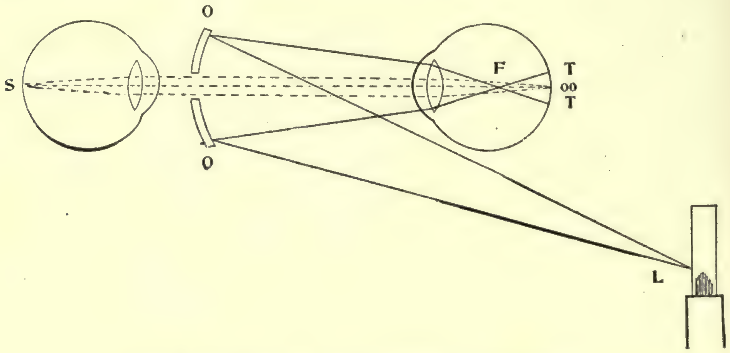


Fig. 366.—Direct Ophthalmoscopy. (BALL.)

Lacrymal Secretion.—Lately it has been shown by Landolt that in the rabbit and the monkey secretory nerves of the lacrymal gland run in the facial nerve. These nerves leave the geniculate ganglion and enter the superficial petrosal. We then find them in the superior maxillary and occasionally in the ophthalmic. He believes these fibers run in the glosso-pharyngeal and then in the facial, but he did not locate the nucleus from which they arise. Eserin increases the *secretion* of tears, atropine decreases it.

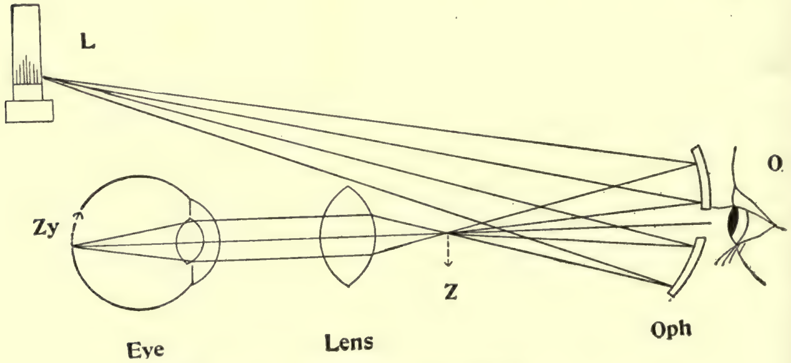


Fig. 367.—Indirect Ophthalmoscopy. (BALL.)

Ophthalmoscope.—This is a small concave mirror by means of which rays of light are directed through the pupil of the eye so that the deep parts are illuminated and made visible. There is a hole in the center of the mirror through which the examiner looks. But the ophthalmoscope may be used with or without lenses. Without lenses the ophthalmoscope gives an erect image. If, however, we use a convex lens over the central aperture of the ophthalmoscopic mirror the observer sees a re-inverted image. If a concave lens is used over the aperture of the ophthalmoscopic mirror there is seen an erect image considerably magnified. The instrument is usually fitted with a series of concave and convex mirrors, which can be revolved in front of the central aperture of the mirror.

If the observer is myopic he can use the concave lenses to correct his myopia. If he is long-sighted, he corrects it by means of one of the convex lenses.

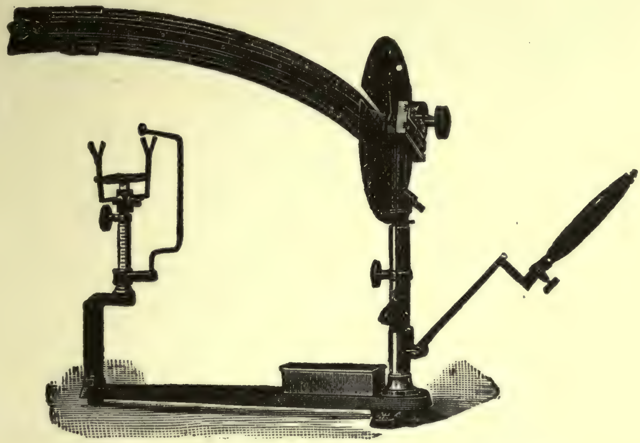


Fig. 368.—The McHardy Perimeter. (Brown.)

If the eye examined be short- or long-sighted, the retinal image could not be brought into focus with the mirror alone, but the examiner can adjust his concave or convex disc, as the case may be, and find a lens to correct the short or long sight of the eye examined.

In this way the ophthalmoscope may be used to measure the degree of myopia or hypermetropia of the eye examined.

Perimeter.—It has been noted that by the peripheral parts of the retina a person can observe pretty definitely the form and color of objects. To determine just how far this field of indirect vision extends in every direction from the visual axis is to locate, by the perimeter, the field of indirect vision. The instrument devised for this purpose is called the perimeter.

With the perimeter the eye is made to view a fixed point from which a quadrant proceeds so that the eye lies in the center of it. Around the fixed point the quadrant rotates, and this circumscribes the surface of a hemisphere in the center of which the eye is located. From this fixed point objects are slid on semicircular arms and are gradually placed more toward the periphery of the field of vision until the object is no longer noticed. Then by moving the semicircular arm in different meridians of the field of vision we obtain what is called the field of vision. The field of vision is more extended below and to the outer side. It is narrowed above by the brow; below by the cheek and the nose.

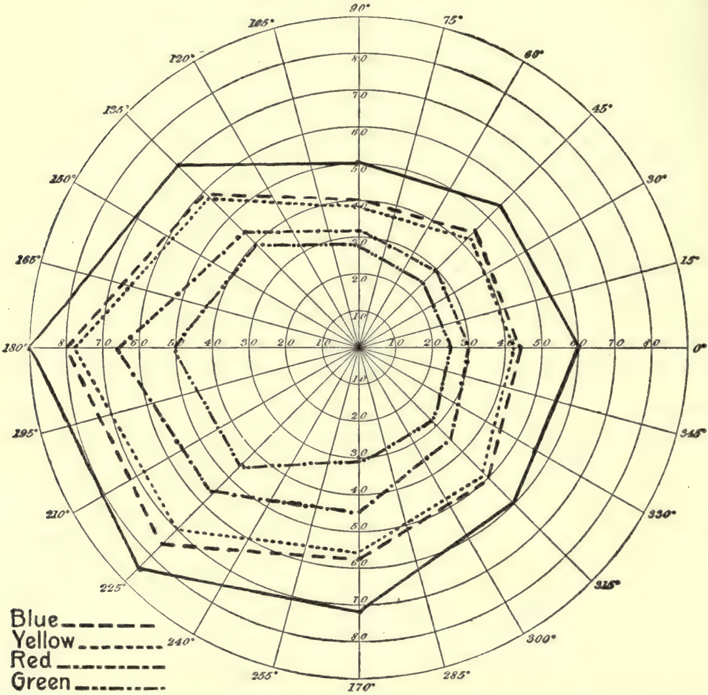


Fig. 369.—Diagram of the Normal Visual Field for White and Colors. (Jennings.)

The outer continuous line indicates the limit of the field for white, and the broken lines indicate the limits of the color fields.

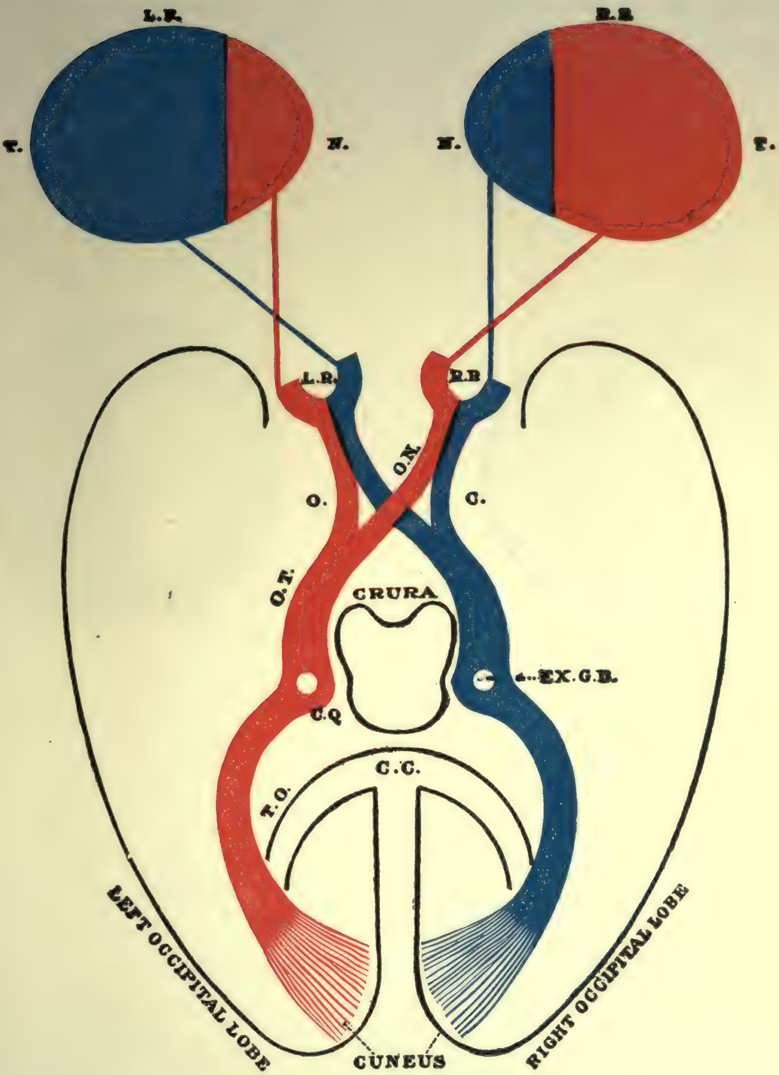

L.F.
R.F.
T.
N.
N.
T.
L.R.
R.R.
O.N.
O.
C.
O.T.
CRURA
EX.G.B.
C.Q
C.C.
T.O.
LEFT OCCIPITAL LOBE
RIGHT OCCIPITAL LOBE
CUNEUS

Fig. 370.—Diagram of the Visual Tract. (Ball.)

R.F., Right visual field. *L.F.*, Left visual field. *N*, Nasal side. *T*, Temporal side. *R.R.*, Right retina. *L.R.*, Left retina. *O.C.*, Optic chiasm. *O.N.*, Optic nerve. *O.T.*, Optic tract. *C.Q.*, Corpora quadrigemina. *Ex.G.B.*, External geniculate body. *T.O.*, Optic thalamus. *C.C.*, Corpus callosum.

Visual Field.—The boundary of the visual field of white light crosses the upper vertical meridian at 55°, the median meridian at 60°, the lower vertical meridian at 70°, and the external meridian beyond 90°. The field for yellow light is within that for white, the field for blue light within that for yellow, the field for red within that for yellow, and the field for green is much smaller.

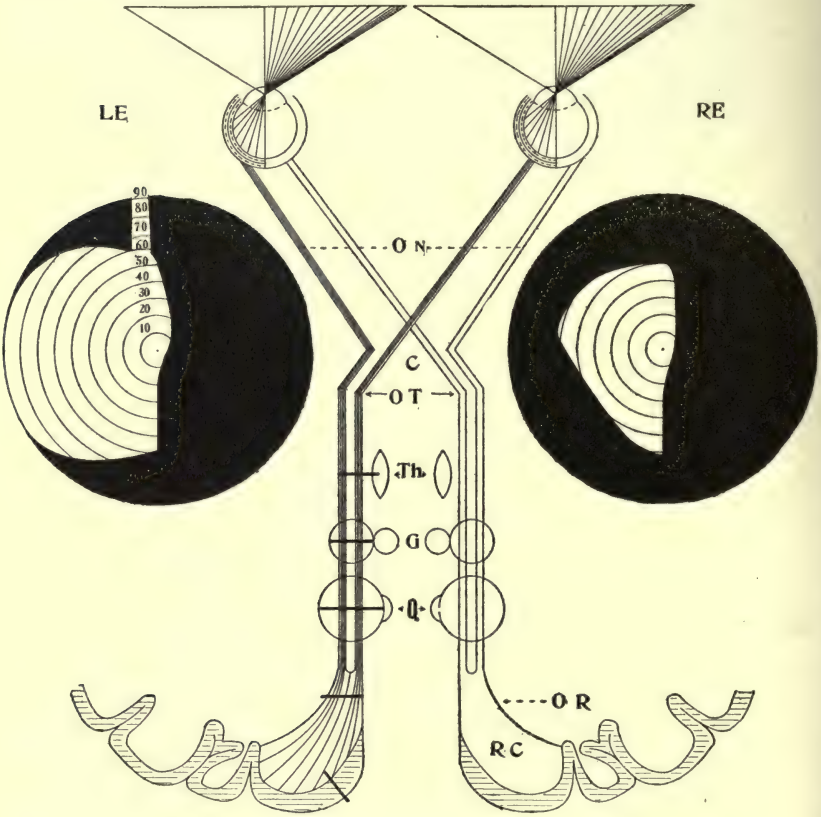


Fig. 371.—Diagram of Right Homonymous Hemianopsia and of the sites of lesions which may cause it. (Ball.)

RE, Right eye. *LE*, Left eye. *ON*, Optic nerve. *C*, Chiasma. *OT*, Optic tract. *Th*, Thalami optici. *G*, Corpora geniculata. *Q*, Corpora quadrigemina. *RC*, Right cuneus. *OR*, Optic radiations.

Pathological.—Argyll-Robertson Pupil.—Here there is no contraction of the pupil to light (no light-reflex); but it does contract when the accommodation is called into play for near objects, it has accommodation-reflex. It occurs in locomotor ataxia and in paresis. Both pupils act, though only one retina is stimulated, owing to the intercentral coupling of the two constricting centers of the pupil. In dyspnœa the pupil dilates, but when asphyxia ensues the dilatation diminishes. Atropine paralyzes the oculomotorius terminals (thus paralyzing accommodation), but after its section the dilatation of the pupil is still further increased by atropine; hence it must be an action on the dilating fibers. Eserin, a myotic, contracts the pupil, due to stimulation of the oculomotor. The anæsthetics contract the pupil, but when their action is deep they dilate it.

WERNICKE'S HEMIOPIA PUPILLARY REACTION.—If the light is thrown on the hemianopic half of the retina, the pupil remains inactive. Here there is an interruption in the path between the retina and the geniculate bodies; the hemiopia is not central, but due to a lesion in the tract of the optic nerve. If the light is thrown on the sensitive half of the retina, the pupil immediately contracts.

CHAPTER XX.

CRANIAL NERVES.

THE cranial nerves are twelve pairs of nerves which reach their respective terminations after passage through foramina located in the base of the cranium. They are designated *numerically,* beginning from the anterior portion of the base of the brain backward, as well as by *names* dependent upon their functions and distribution. They are as follows:—

1. Olfactory.
2. Optic.
3. Motor oculi.
4. Pathetic.
5. Trifacial.
6. Abducent.
7. Facial.
8. Auditory.
9. Glosso-pharyngeal.
10. Pneumogastric.
11. Spinal accessory.
12. Hypoglossal.

Origin of the Cranial Nerves.—Upon examination, each cranial nerve is found to possess *a point of superficial origin* as well as *a nucleus of deep origin.*

The *superficial origin* is that point upon the brain's surface where each nerve emerges. This is but the apparent origin of each pair of nerves, since their individual fibers may be traced more deeply.

Each cranial nerve has a special nucleus of gray matter lying deeply within the brain-substance. The nucleus consists of a collection of cells from whose prolongations spring the axis-cylinders which constitute the fibers of the nerves.

The gray masses which represent the prolongations of the anterior horns of the cord into the medulla oblongata form the nuclei of origin of the *cranial motor nerves.* The base, separated from the head of the horn by decussation of the pyramidal columns, remains contiguous to the central canal. It is prolonged in its entirety upon the floor of the fourth ventricle, lying upon each side of the raphé. Beneath the trigonum hypoglossi lies the nucleus of the hypoglossal; beneath the eminentia teres is found the common nucleus of the facial and abducent; the nuclei of the oculomotor and pathetic lie upon each side of the aqueduct.

The head of the anterior horn, cut into fragments by the motor decussation, forms that which is known as the antero-lateral nucleus. This is the motor nucleus of the mixed nerves. By its most internal parts it represents the accessory or anterior nucleus of the hypoglossus; farther up, the proper nucleus of the facial; and in the pons there is found the motor root of the trigeminus.

The gray masses of the posterior horns of the cord, prolonged into the medulla oblongata and cut by the sensory decussation or fillet, form the *sensitive nuclei* of the cranial nerves. The base of the posterior horn forms the sensory nucleus of the mixed nerves, namely: glosso-pharyngeal, vagus, and spinal accessory. Above these nuclei there is a gray layer which represents the oblongata center of the internal root of the auditory; higher still arises the sensory nucleus of the trigeminus. The head of this horn, under the name of gray nucleus of Rolando, ascends in the pons to form the ascending root of the trigeminus.

Among the twelve pairs of cranial nerves, ten have their points of origin in cells of the gray matter of the cord. This latter has been prolonged into the medulla oblongata and pons in the form of four motor and sensory columns. Thus these cranial nerves are comparable to spinal nerves.

COMPARABLE TO SPINAL NERVES.—The law of double root is as applicable here as to the spinal nerves. Those nerves destined for movement originate in the prolongations of the anterior horns, while those which preside over sensibility take their origin in gray matter of the medulla and pons which has sprung from the posterior horns of the spinal cord.

Point of Difference.—There is this difference, however, between cranial and spinal nerves: In the spinal nerves, the two roots are intimately united just outside of the spinal-cord substance to form a mixed nerve. In the case of the cranial nerves the posterior sensory roots and the anterior motor roots remain, for the most part, separated to form nerves that are either exclusively motor or exclusively sensory. In other words, the cranial nerves represent the dissociated spinal nerves in which the anterior and posterior roots remain habitually isolated to form nerves which are either fine conductors of motion or sensation, dependent upon their source.

In the hypoglossal alone are fulfilled the true characteristics, for in numerous cases it is found to have a ganglion upon its posterior root.

The mesencephalon has been considered to possess parallel features with the spinal cord, in that it is formed of a series of segments corresponding to the cranial nerves. As the student already knows, each *spinal nucleus* has peripheral conductors which bring to the cord its sensory impressions, and motor nerves to conduct to the muscles the motor reactions. In the same way the central conductors of the brain bring to it sensory impressions and by its motor fibers carry out motion. Hence it results that all of the sensory fibers of centripetal course have their origin, not in the gray nuclei of the medulla oblongata, but in the ganglia annexed to the dorsal roots of the cranial nerves.

The oblongata nuclei are but terminal nuclei, for in them the sensory fibers terminate by fine arborizations which surround the central cells without penetrating them. The termination is identical with that of the sensory roots of the spinal nerve.

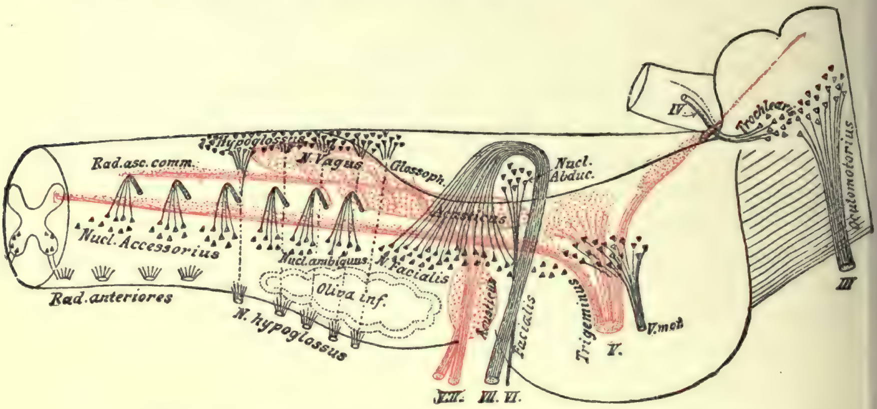

Rad.asc.comm.
Hypoglossus
N. Vagus
Glossoph.
IV.
Trochlearis
Oculomotorius
Nucl. Abduc.
Acusticus
Nucl. Accessorius
Nucl. ambiguus
N. Facialis
III
Rad. anteriores
Oliva inf.
N. hypoglossus
Acusticus
Facialis
Trigeminus
V. mot.
V.
VIII.
VII. VI.

Fig. 372.—Position of the Nuclei of the Cranial Nerves. (After Edinger.)

The medulla oblongata and pons are imagined as transparent. The nuclei of origin (motor), black; the end nuclei (sensory), red.

The sensory fibers of the tenth, ninth, seventh, and fifth pairs of cranial nerves, as well as that of the auditory, originate in their respective ganglia. Thus, there is the jugular for the tenth pair, the jugular and petrosal for the ninth pair, the geniculate for the seventh, Gasserian for the fifth, and Scarpa's and spiral ganglia for the eighth pair.

On the contrary, the motor fibers of the cranial nerves arise in the central cells of the medulla and pons, just like the motor fibers of the spinal cord. Thus, fine anatomy demonstrates that the cranial, like the spinal, nerves have *double roots.*

Decussations.—The afferent or sensory cranial nerves do not decussate. Of the motor cranial nerves, the third and fourth, the motor root of the fifth, the seventh, the motor root of the vagus, the glosso-pharyngeal, and the hypoglossal *decussate* partially. The pathetic decussates completely in the valve of Vieussens. The last-named nerve springs from the oculomotor nucleus united with that of the pathetic. These portions of gray matter are a direct part of the anterior horn of the spinal cord lying beneath the aqueduct of Sylvius.

In Chapters XVII and XIX were considered the *olfactory,* or first pair of cranial nerves, and the *optic,* or second pair; so that in this chapter there will be taken up, first, the motor oculi, or third pair of cranial nerves.

THIRD PAIR, OR MOTOR OCULI NERVE.

This nerve arises from a nucleus situated between the corpora quadrigemina and beneath the floor of the aqueduct of Sylvius. Beneath the posterior end of the anterior corpus quadrigeminum this nucleus becomes continuous with the nucleus of the trochlearis or patheticus. The oculomotor nuclei consist (1) of a group of cells concerned in accommodation; (2) those concerned in the reflex action of the iris to light; (3) the innervation of all the muscles of the eye except the external rectus and superior oblique. The neuraxons of these cells pass by and through the red nucleus and emerge at the inner side of the cerebral crura, to pass through the interpeduncular space along the outer boundary of the cavernous sinus; they then enter the sphenoidal fissure, and go to the muscles of the eyeball, except the external rectus and superior oblique. It also gives fibers to the ciliary muscle and the sphincter of the pupil and a branch to the elevators of the upper lid.

The posterior longitudinal bundle is also connected with the nuclei of the third, fourth, and sixth nerves. The oculomotor nucleus also has a connection with the optic neurons in the anterior corpora quadrigemina. In the cavernous sinus it receives filaments coming from the carotid branches of the great sympathetic and a branch from the ophthalmic of the trigeminus.

Functions.—From a functional point of view, it may be said that the motor oculi is devoted exclusively, in conjunction with the fourth and sixth pairs of nerves, to making the sight perfect. With these nerves it concurs to regulate the varied movements which allow the eye to act as a telescope upon a support that is furnished with numerous articulations. By means of these muscles and nerves of the orbit the individual is enabled to remove the visual field from place to place and in all directions to any objects which he might wish to examine.

For its part, the motor oculi allows the eye to see particularly objects that are situated high or low or at one side. However, it has a most important function in the harmony of the associated movements by which two images fall upon identical points of the retinæ of the two eyes, thus causing but one and the same impression.

The third pair of nerves manages to regulate the amount of light which falls upon the retinæ. Its function in this capacity is to protect the optic nerve against a too intense excitement from excessive light. By contracting the pupil it lessens the pencil of light which penetrates into the depths of the ocular globe.

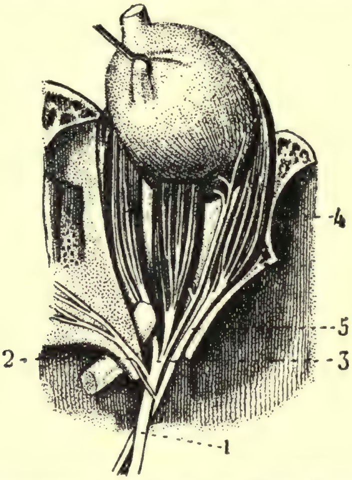


Fig. 373.—Distribution of the Third and Sixth Nerves in the Orbit. (Lèveillé.)

1, The third nerve. 2, Its superior division. 3, Its inferior division. 4, Branch to the inferior oblique muscle. 5, The sixth nerve distributed to the external rectus muscle.

On the contrary, it is the sympathetic which produces dilatation of the pupil so that the retina may receive all of the light which can be reflected from obscure objects. For the accomplishment of contraction and dilatation of the pupil it must be remembered that the iris comprises two kinds of muscular fibers: circular and radiating. The former are connected with the motor oculi; the latter with the sympathetic.

Finally, the third nerve is considered to have an important function in the act of accommodation.

Pathology.—The motor oculi is frequently a sufferer by reason of its situation and course. It is often compressed by tumors at the base of the brain. In its passage through the sinus cavernosus it is exposed to compression by a thrombosis of this venous canal.

The course of the third nerve through the interpeduncular space makes it play a considerable part in pathology. This is the place of predilection for meningitic deposits. This segment of the nerve is most frequently compressed in the exudates of tubercular meningitis. It is also the point of attack of constitutional syphilis, particularly during the tertiary period; this is a chronic meningitis which has its principal focus at the interpeduncular space as an exudate. Diphtheritic infection often attacks the third pair of cranial nerves.

Paralysis of the oculomotor gives rise to external squint. Its irritation causes internal squint, and also contraction of the pupil, or myosis. The eye deviates outward in paralysis, due to the action of the external rectus not being antagonized by the internal rectus.

Diplopia.—The deviation of one of the eyes does not permit the maintenance of parallelism of the visual axes. Without this coincidence the two images will not fall upon identical points in the retina. Hence all objects seen will be double. This symptom, known as *diplopia,* renders the sight very uncertain and often produces vertigo.

Should the paralysis be general, so that it comprises the elevator of the lid, Nature brings for itself a remedy for the defect of diplopia by suppressing the vision of one eye. It does this by letting the lid fall over the deviating eye. This drooping of the lid gives the condition known as *ptosis.*

Stimulation of the motor fibers of the third can be produced reflexly by teething or intestinal irritations of children; hence their squint. Chronic spasms of the eye-muscles which are involuntary are called by the name *nystagmus.*

Drugs.—Atropine paralyzes the intra-ocular ends of the motor oculi; *Calabar bean* stimulates them or paralyzes the sympathetic.

FOURTH PAIR, OR PATHETIC NERVE.

Distribution.—The pathetic supplies the superior oblique muscle.

Physiology.—If the peripheral end of the pathetic be electrically irritated, the superior oblique muscle contracts and turns the eyeball downward and outward.

The pathetic is a nerve that is especially endowed for the realization of simple vision with the two eyes in inclined positions of the head. It is impossible for an individual to carry one eye downward and outward. That is, he cannot make a movement directed by the superior oblique and still keep the head perfectly vertical. It becomes necessary that the head be inclined to one side, and at the time this inclination is produced the rotation of the eyeball occurs without the will having the power to prevent it. By the very act of inclination of the head the necessary parallelism of the two eyes is positively destroyed; hence this involuntary action of the superior oblique to place the visual axes upon the same plane.

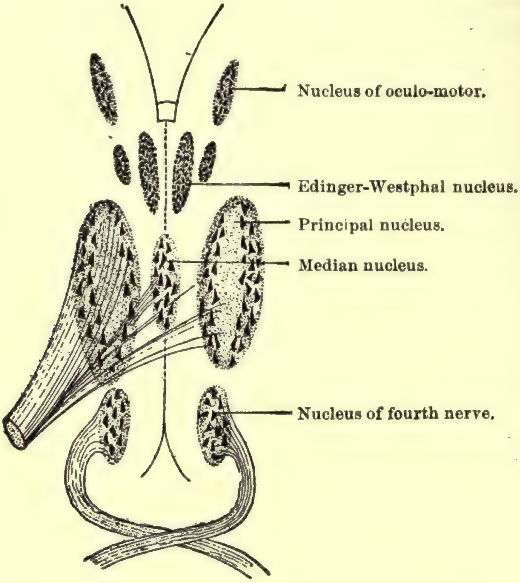


Fig. 374.—Nuclei of Origin of the Third and Fourth Nerves.
(Poirier and Charpy.)

The fourth pair of cranial nerves arise from a collection of cells beneath the anterior part of the posterior corpus quadrigeminum. It completely decussates in the superior medullary velum. It starts behind the quadrigeminal body and then appears like a white thread winding around the outer side of the crus of the cerebrum. It then pierces the dura mater, runs along the outer wall of the cavernous sinus, and enters the sphenoidal foramen with the oculomotor and abducent. It supplies the superior oblique muscle of the eye.

Pathology.—Usually the first sign of any disorder of the pathetic is a giddiness when ascending or descending a stairs, owing to the double vision that occurs when the patient, in going down, looks at his steps.

To overcome this diplopia he gives to his head a position that is quite characteristic. He holds his head bent forward and directed to the ground. This position overcomes the necessity of moving the eyeballs from above downward and so minimizes the liability to diplopia.

SIXTH PAIR, OR ABDUCENT NERVE.

This nerve arises from a collection of cells seated beneath the floor of the fourth ventricle below the striæ acusticæ. The loop of the facial incloses it. The abducent emerges between the summits of the pyramidal bodies of the medulla oblongata and the pons. As a threadlike nerve it goes through the cavernous sinus and through the sphenoidal foramen to the external rectus. The nucleus of the abducent has a connection with the posterior longitudinal bundle of fibers to the opposite oculomotor nucleus, thus permitting associated movements of the eyeball. The pontal olives are connected by fibers with the oculomotor nucleus. And these olives are also connected with the auditory nuclei and these nuclei are connected with the cerebellum, so that there is an association between the motor nerves of the eye, the auditory nerves, and the cerebellum.

Physiology.—The sixth nerve is exclusively motor. It has for its only aim to excite the external rectus. When the nerve is strongly galvanized the eyeball deviates outward. Its section, on the contrary, produces an internal strabismus. It is especially adapted for seeing objects placed to one side. In general, the abducent is but one of the elements for the exercise of perfect vision.

Pathology.—Paralysis is the most common manifestation in the sixth pair. A considerable concussion of the orbital cavity, especially when it is upon the external side, will particularly paralyze the abducent. Unilateral paralyses of this nerve are usually of peripheral origin. Bilateral paralysis is generally due to central disturbance. The most prominent symptom of this affection is an internal or convergent strabismus. The eye is held inward by the tonus of the *rectus internus,* so that not more than one part of the cornea is perceived.

CONJUGATE DEVIATION.

Waller explains this as follows: The two eyes are exactly equal and parallel for different directions of distant vision. Both eyes are turned to the right or to the left, up or down, so that the object fixed gives images on corresponding parts of both retinæ. In movements directly upward or downward muscles of the same name in each eye are associated in action; but in lateral movements the association is asymmetrical: *e.g.*, the external rectus of one eye acts with the internal rectus of the other, and the peculiarity of this associated action seems still more striking when it is remembered that the external rectus is supplied by the sixth nerve, while the internal rectus is supplied by the third. A similar, if less striking, association of asymmetrical muscles on the two sides occurs in the rotation of the head and neck, which are turned to the right by the right inferior oblique and the left sterno-mastoid muscles, and to the left by the left inferior oblique and the right sterno-mastoid. In looking to the right we contract the right external and left internal recti: *i.e.*, impulses pass through the right sixth nerve and the left third, possibly from the left and from the right side, respectively, of the motor cortex, but more probably from only the left motor cortex, in which case we must suppose that certain nerve-fibers cross twice: once between the cortex and bulbar nucleus and a second time between the nucleus and nerve-termination. Unilateral convulsions of cortical origin are accompanied by rotation of the head and eyes toward the convulsed side: *i.e.*, away from the cerebral lesion. Thus a discharging lesion of the right motor cortex causes convulsions of the left side of the body, with rotation of the eyes to the left. This is a "conjugate deviation." A destructive lesion of the right motor cortex causes paralysis of the left side of the body, with rotation of the eyes to the right. The peculiarity in this case is that there is a cessation of action along the left sixth nerve (external rectus) and the right third nerve (internal rectus), the deviation of the eyes to the right being caused by the unbalanced action of the muscles, which rotate the eyes to the right.

FIFTH PAIR, TRIGEMINUS, OR TRIFACIAL NERVE.

The fifth pair of nerves, like a spinal nerve, has two roots: an anterior motor one and a posterior sensory one. The neuraxons of the motor nucleus in the pons make up the motor root. The sensory arises in the Gasserian ganglion, and, like a posterior-root

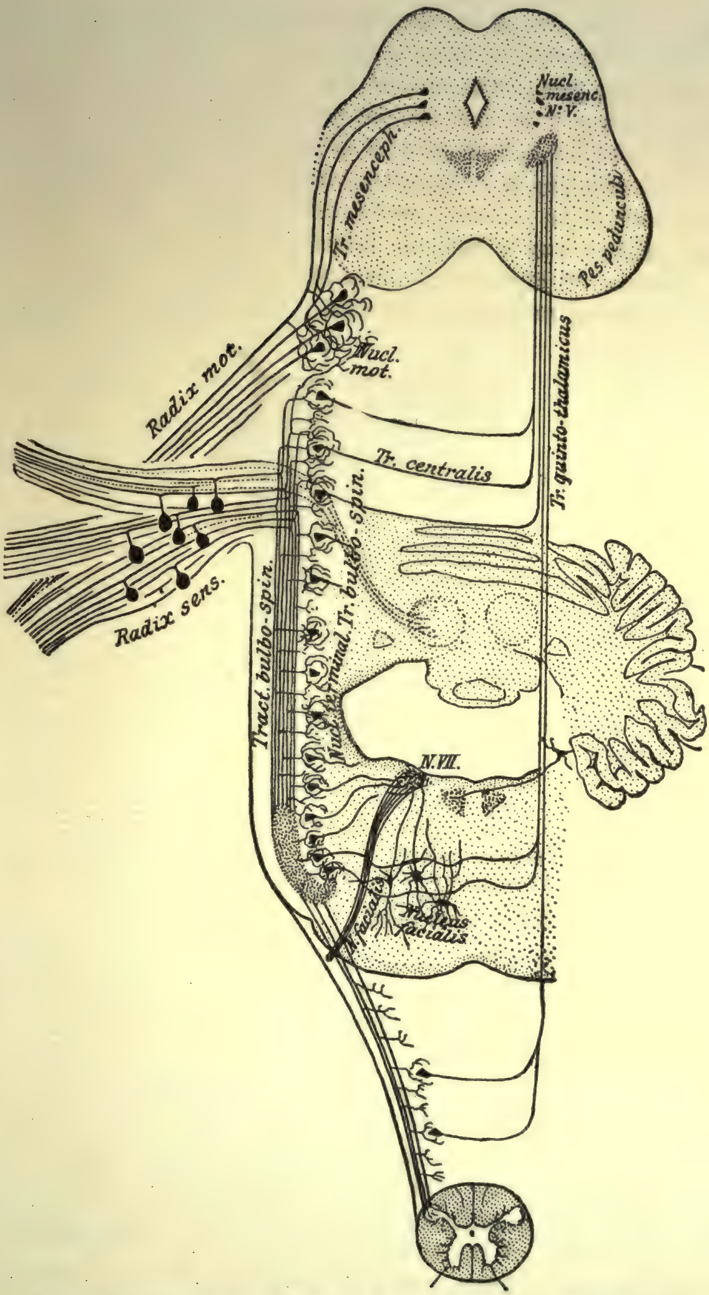

Nucl. mesenc. N° V.
Tr. mesenceph
Pes pedunculi
Nucl. mot.
Radix mot.
Tr. centralis
Tr. quinto-thalamicus
Tr. bulbo-spin.
Radix sens.
Tract. bulbo-spin.
Nucl. terminal. Tr. bulbo-spin.
N. VII.
N. facialis
Nucleus facialis

Fig. 375.—The Origin of the Trigeminal Nerve. (Edinger.)

ganglion, its neuraxons are divided, one part going to the skin of the face and the other, running toward the pons, also divides into two parts, one going upward and the other downward. The gelatinous substance of Rolando on the posterior horn receives the fibers running downward, which arborize around the cells.

The descending part of the trigeminus, known as the ascending root, extends down to the second cervical vertebra, continually giving off collaterals as it descends, which arborize around the gelatinous substance of Rolando of the posterior horn, thus making the lower trigeminal nucleus a long one. The descending branch also has collaterals, which arborize around the motor nuclei of the hypoglossal, facial, and trifacial. The neuraxons of the sensory nuclei in which the trigeminus ends decussate and go to the cortex in the fillet.

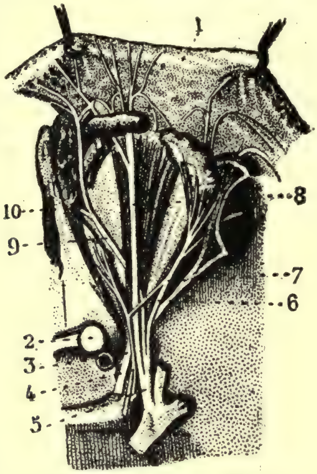


Fig. 376.—Ophthalmic Division of the Fifth Nerve. (Leveillé.)

1, Skin of the forehead turned down. 2, Optic nerve. 3, Third nerve. 4, Fourth nerve. 5, Ophthalmic division of the fifth nerve. 6, Lacrymal branch. 7, Union of the fourth nerve with the lacrymal branch of the fifth. 8, Frontal. 9, Nasal. 10, Internal branch of nasal.

Cortical Connection.—The sensory path ends in the inferior part of the central region of the cortex, going up in the fillet and the thalamus. The nucleus of the motor root lies in the pons, near the sensory nucleus of the trigeminus and back of the nucleus of the facial, of which it is probably a part. There is another nucleus, the accessory nucleus of the motor nucleus, which is situated beneath the aqueduct of Sylvius, and which sends descending fibers to the motor nucleus.

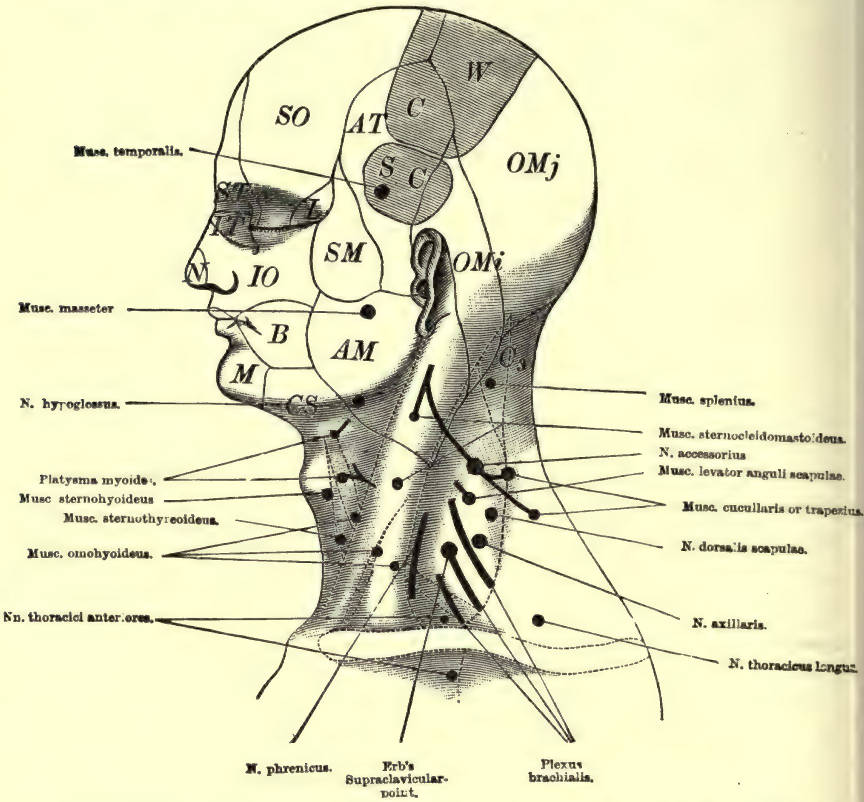
The trigeminus emerges from the pons by two roots: a large sensory root and a small motor root. The large root has the Gasserian, or semilunar, ganglion, while the small root runs beneath it. From the semilunar ganglion emanate the ophthalmic, superior maxillary, and a third branch, which joins the small root of the trifacial to form the inferior maxillary nerve. The nasal branch of the ophthalmic, ciliary, or lenticular ganglion gives off the ciliary nerves for the ciliary muscle and iris. This ganglion receives motor fibers from the oculomotor nerve and branches from the sympathetic. The superior maxillary branch passes through the rotund foramen of the sphenoid bone and gives off dental nerves and spheno-palatine nerves which go to Meckel's, or the spheno-palatine, ganglion. It gives off nasal, palatine, and pterygoid nerves. The pterygoid nerve gives off a branch, the great petrosal, which enters the cranial cavity through the cavity of the foramen lacerum and enters a canal on the front of the petrous portion of the temporal bone to join the facial nerve. The inferior maxillary nerve is formed of the small motor root of the trigeminus and a third branch of the semilunar ganglion, and makes its exit from the skull by the oval foramen. It gives off the auriculo-temporal and the lingual nerve, which in its course is joined by the chorda tympani of the facial and the inferior dental nerves. On the sensory division of the inferior maxillary nerve is seated the otic, or ganglion of Arnold. From it emanates the small petrosal nerve, which enters the cranium through a fine canal in the spinous process of the sphenoid bone and then courses along a canal in front of the petrous portion of the temporal bone to join the facial. The otic ganglion gives out filaments to the tensor palati and tensor tympani muscles.

Physiology.—From the point of view of *general sensibility* the trigeminus possesses a considerable domain. To it alone is intrusted the giving of general sensibility to nearly all parts which enter into the composition of the head. In the external covering of the head but one region escapes it. This is the lateral and posterior part of the hairy scalp, the innervation for the latter coming from the cervical nerves.

As to mucous-membrane sensibility, trifacial innervation comes only to the posterior third of the tongue, where the glosso-pharyngeal innervates the palate, with the middle and inferior parts of the pharynx.

These points being eliminated, it gives tactile sensibility not only to the skin, but also to all of the tissues of the head, comprising the glands, meninges, organs of sense, bone, and dental pulp.

Reflex Relations.—By reason of the ciliary filaments the trigeminus is in particular reflex relation with the motor oculi and sympathetic. Because of the ramifications of the trifacial branches in the mucous membrane of the nose there is established a very intimate relation with the expiratory muscles and nerves. Even the slightest touch may occasion a sudden and violent sneeze. A close relation-


W
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Musc. temporalis.
Musc. masseter
N. hypoglossus.
Platysma myoides.
Musc sternohyoideus
Musc. sternothyreoideus.
Musc. omohyoideus.
Nn. thoracici anteriores.
N. phrenicus.
Erb's Supraclavicular-point.
Plexus brachialis.
Musc. splenius.
Musc. sternocleidomastoideus.
N. accessorius
Musc. levator anguli scapulae.
Musc. cucullaris or trapezius.
N. dorsalis scapulae.
N. axillaris.
N. thoracicus longus.

Fig. 377.—Distribution of the Sensory Nerves of the Head, together with the Situation of the Motor Points on the Neck. (Landois.)

SO, Distribution of the supraorbital nerve. *ST*, Supratrochlear nerve. *IT*, Infratrochlear nerve. *L*, Lacrymal nerve. *N*, Ethmoid nerve. *IO*, Infraorbital nerve. *B*, Buccinator nerve. *SM*, Subcutaneous malar nerve. *AT*, Auriculotemporal nerve. *AM*, Great auricular nerve. *OMj*, Greater occipital nerve. *OMi*, Lesser occipital nerve. C_3, Third cervical nerve. *CS*, Cutaneous branches of the cervical nerves. *CW*, Situation of the central convolutions of the cerebral hemisphere. *SC*, Situation of the speech-center (third frontal convolution).

ship exists between this nerve and the muscles and nerves of deglutition.

A remarkable fact in connection with the trigeminus is its great functional resistance to various poisons which are capable of paralyzing nerves of sensation. While all other regions of the body show the effects of anæsthetics, those under the dominion of the trigeminus still preserve a high degree of sensibility. Even though a patient be anæsthetized with chloroform, yet will he perceive punctures in the temples and frontal regions. This occurs in spite of the fact that sensations are not perceived elsewhere.

Motor Functions.—By its short root the trigeminus holds under its power the movements of elevation, depression, and rotation of the lower jaw. If this root be cut, it is found that the muscles concerned in the performance of the above-mentioned movements are paralyzed. The lower jaw remains passively separated from the upper.

Trophic Function.—Within twenty-four hours after intracranial section of the trigeminus, the cornea becomes opaque. At the end of five or six days the cornea becomes very white in color. The iris becomes inflamed and covered with false membranes. In about eight days the cornea becomes detached and the contents of the eye escape.

The suppression of the fifth pair is followed by remarkable alterations in the Schneiderian membrane. It becomes spongy, and bleeds upon the least touch. The place where the olfactory bulbs lie is completely changed. Thus the acts of olfaction and vision are indirectly affected.

Pathology.—By reason of the intimate association of the trigeminus, and its Gasserian ganglion, with the petrous portion of the temporal bone, it is exposed to all of the shocks and blows that are able to fracture this bone.

The relations of the trigeminus with its meninges are very apt to be disturbed seriously by the presence of tumors. The false membranes which are found in meningitis compress it and so produce atrophy. The exudates of tubercular meningitis very often produce anæsthesia of the face.

The fifth pair is most often the seat of either excessive sensibility or paralysis. It is, perhaps, the one nerve which is the most frequently affected in neuralgia. The relative nearness of the trigeminus to its sensory center probably explains the acuteness of the pains in neuralgia.

SEVENTH PAIR, FACIAL NERVE, OR PORTIO DURA.

The facial nerve arises from a nucleus beneath the floor of the fourth ventricle. This nerve contains a motor and a sensory root. The sensory root comes from the cells of the geniculate ganglion, and is called the nerve of Wrisberg. The motor pontal nucleus gives off the neuraxons of the motor root. The motor nucleus is thought to be the upward part of the nucleus ambiguus, which originates the motor fibers in the vagus and glosso-pharyngeal nerves. The neuraxons of the motor nucleus form a distinct knee, which uprising on the floor of the fourth ventricle is known as the eminentia teres. The facial nerve in its course to the periphery makes a peculiar loop, or knee, inclosing the nucleus of the abducent, and emerges from a depression back of the pons between the olivary and restiform bodies, enters the internal auditory meatus with the auditory nerve, leaves the auditory nerve, enters the Fallopian canal, and makes its exit by the stylomastoid foramen to go to the muscles of the face. The nerve of Wrisberg, or the sensory part of the facial, is made up of neuraxons from the cells of the geniculate ganglion seated in the Fallopian canal. The auditory nerve is also called portio mollis, and it lies to the outer side of the facial,—the portio dura,—and between the two is the pars intermedia portio inter duram et mollem of Wrisberg, which extends from the medulla to join the facial in the internal auditory meatus. It is connected with both auditory and facial nerves, between which it lies. The central neuraxons of the geniculate ganglion or the nerve of Wrisberg go to the fasciculus solitarius or the vagus and glosso-pharyngeal roots. The peripheral neuraxons of the geniculate ganglion join the facial, and Duval states that they go to form the nerve of taste: the chorda tympani.

In the hiatus Fallopii the *great petrosal* nerve branches off from the facial. It, in conjunction with a filament from the glosso-pharyngeal and another from the sympathetic, passes over to join the ganglion of Meckel.

The *small petrosal* leaves the aqueduct by a particular opening to end in the otic ganglion.

Cortical Connection.—The motor path from the cortex to the facial nucleus arises from the inferior part of the central convolutions.

Chorda Tympani.—A few millimeters above the stylo-mastoid foramen the facial gives off a branch of very considerable size: the *chorda tympani.* It ascends into the cavity of the tympanum. It passes between the malleus and incus, giving a branch to the latter, and then enters the zygomatic fossa. The chorda tympani then descends between the two pterygoid muscles to meet the nerve of taste. After communicating with the latter it accompanies it to the submaxillary gland. There it joins the submaxillary ganglion to terminate in the lingual nerve.

Physiology.—While the trigeminus is responsible for the sensibility of the face, the facial presides over the contraction of the facial muscles of expression.

The facial nerve is purely motor, and so has nothing to do with the transmission of sensory impressions developed upon the face. After its section the skin still preserves all of its sensibility. On the other hand, after section of the trifacial it completely disappears. Though the facial does not transmit sensory impressions, yet in itself it is sensitive because of the branches which it receives from the trigeminus. If the nerve be pinched, the animal shows signs of pain.

Pathology.—The facial is the motor nerve which suffers most easily from the influence of cold. Facial paralysis, or Bell's palsy, may occur very easily when draughts from a window blow upon the face.

When the paralysis is unilateral, the face is drawn toward the sound side. The labial commissure on the paralyzed side is lower than that on the other side, thus giving to the mouth an oblique direction.

Bell's paralysis is usually due to a cold draught of air striking the nerve at its exit from the stylo-mastoid foramen. When the cause is seated in the brain the external rectus is usually affected, because its nerve is also involved and usually there is paralysis of the opposite half of the body, or crossed paralysis. Here the lesion is in the pons. If the lesion is seated in the petrous portion of the temporal bone, there is not only facial palsy, but also loss of taste from an involvement of the chorda tympani.

EIGHTH PAIR, OR AUDITORY NERVE.

The anatomy and function of this nerve have been discussed in Chapter XVIII.

NINTH PAIR, OR GLOSSO-PHARYNGEAL NERVE.

The glosso-pharyngeal nerve is a nerve of both motion and sensation.

Cortical Connections.—The sensory ascending path of the ninth nerve ends in the inferior part of the central region of the cortex and in the immediate neighborhood of the posterior part of the second and third frontal convolutions.

The nucleus ambiguus gives off neuraxons to form its motor root. The sensory neuraxons arise from the jugular and petrosal ganglions and arborize about two sensory nuclei in the medulla oblongata. The lower sensory end nucleus produces an elevation on the floor of the fourth ventricle, and is called the ala-cinerea. The upper nucleus is also connected with sensory neuraxons of glosso-pharyngeal nerves, while the lower portion of this nucleus is in relation with the vagus. The second nucleus is called the vertical nucleus, the fasciculus solitarius, the combined descending root of the pneumogastric and glosso-pharyngeal nerves, or the respiratory bundle. This respiratory tract extends from the olive down the spine to the eighth cervical nerve. This respiratory bundle of Gierke may associate the nuclei coördinating the various respiratory muscles. The glosso-pharyngeal nerve arises by a half-dozen cords from the restiform body and goes through the jugular foramen into the vagus, where it has a small ganglion: the jugular. As it emerges from the jugular foramen there is developed the petrosal ganglion, or ganglion of Andersch.

Nerve of Jacobson.—This same ganglion gives origin to the nerve of Jacobson. It enters the cavity of the tympanum by way of an opening in its floor, where it divides into three filaments. These are distributed, one to the round window, another to the oval window, and the third to the lining membrane of the Eustachian tube and tympanum.

Physiology.—The ninth is a mixed nerve. Its motor properties are distributed to the middle constrictors of the pharynx and the stylo-pharyngeus muscle.

The most important sensory function of the glosso-pharyngeal is the part which it plays in the rôle of the sense of taste.

The ninth nerve has an action upon the blood-vessels of the tongue that is identical with that of the chorda tympani. If the glosso-pharyngeal be cut and its peripheral end stimulated, the tongue becomes a livid red.

Pathology.—In man there are no clear cases recorded where there have been uncomplicated affections of the glosso-pharyngeal.

TENTH PAIR, PNEUMOGASTRIC, OR VAGUS.

Of all of the cranial nerves, the vagus is the most important and has the most functions of a varied nature in clinical study. It is a nerve of motion and sensation.

Cortical Connection.—The motor path to the nucleus of the vagus is from the inferior part of the central convolutions.

The motor neuraxons arise from the nucleus ambiguus. The sensory roots come from the neuraxons of the jugular and petrosal ganglions. The sensory neuraxons have been described under the preceding nerve: the glosso-pharyngeal. The vagus springs by means of from ten to fifteen cords from the groove behind the olivary body and passes through the jugular foramen with the glosso-pharyngeal and spinal accessory nerves. In the jugular foramen it has a ganglion: the jugular ganglion. After it emerges from the foramen it has an enlargement, the gangliform plexus, or ganglion nodosum.

The plexus gives off the *pharyngeal* and *superior laryngeal* nerves.

The pharyngeal nerves, three in number, go down the side of the pharynx to supply the mucous membrane and muscles of the pharynx. The superior laryngeal goes down the side of the larynx. This nerve also furnishes a collateral branch, important from a physiological standpoint, to the crico-thyroid muscle. It then loses itself in the mucous membrane of the larynx.

At the base of the neck the vagus gives off another branch, the *recurrent,* or *inferior laryngeal.* The nerve upon the right side descends in front of the subclavian artery and winds around it posteriorly from beneath. Upon the left side the nerve winds around the arch of the aorta in the same manner.

As collateral branches, the vagus furnishes cardiac fibers, which form the cardiac plexus and are destined to innervate the heart. There are also œsophageal fibers whose terminations are distributed to the œsophagus and trachea.

In the cervical region the tenth pair gives rise to a branch, the *nervus depressor.* It results by the fusion of two fibers: one from the superior laryngeal and the other from the vagus itself. The nervus depressor loses itself in the cardiac tissue of the heart at the level of the aortic and pulmonary orifices.

During the first portion of its course the vagus forms numerous anastomoses. These are with the spinal accessory, the facial, and hypoglossal cranial nerves and with a great number of branches from the various ganglia of the sympathetic system.

In the *thorax* the vagus gives off cardiac and pulmonary branches. These also anastomose with the sympathetics to form numerous plexuses.

The *terminal branches* of the vagus are distributed to the stomach, solar plexus, and also to the hepatic plexus of the sympathetic.

The most striking feature with regard to the vagus is the great number of its anastomoses. It is a very complex nerve and in no part of its course is it exclusively itself.

Physiology.—The relationship existing between the vagus and spinal accessory nerves is a very intimate one by reason of their anastomoses. This makes the determination of the true nature of the vagus one of the difficult problems of physiology.

It is certain that the vagus is endowed with sensibility, for the suppression of the spinal accessory does not deprive the parts of any sensibility in any portion of their common distribution. But, as the spinal accessory is motor and the vagus sensory, it does not necessarily follow that the latter nerve is exclusively sensory and that all movements realized by association should be the special work of the spinal accessory. It was Bernard who first demonstrated that the vagus in itself is a *mixed nerve.* After he had torn out all of the root-fibers of the spinal accessory in animals he found that the motor acts of the larynx persisted in the phenomena of respiration. However, while the vagus in itself is a mixed nerve and has a certain amount of motor functions, yet its principal rôle is of a sensory nature.

The mode of distribution of the vagus indicates that the nerve exercises some action upon (1) the *digestive apparatus,* (2) upon the *respiratory apparatus,* (3) upon the *circulation,* (4) upon the *hepatic apparatus,* and (5) an indirect action upon the kidneys and suprarenal glands.

Pathology.—The recurrent is more liable to be pressed upon by reason of its peculiar course and its direct relations with the great vessels and body of the thyroid. As the vagus is a mixed nerve, it is very evident that compression causes troubles in motion and sensibility, either isolated or conjointly.

Any lesions located at the origin of the vagus cause phenomena of irritation in the whole sphere of distribution of this nerve. Reflexly the vagus is capable of affecting the chorda tympani and increasing the flow of saliva. It is for this reason that intestinal parasites often cause ptyalism.

The sensibility of the branches of the vagus in the stomach remains unconscious during the normal physiological state, when it does not seem to be any greater than that of the sympathetic. During pathological conditions, however, it acquires a high degree of intensity. Thus, in simple wounds of the stomach, without hæmorrhage or peritonitis, the impression carried to the medullary center may be of such a nature as to cause rapid death.

The great frequency of gastralgia is due to an affection of the terminal branches of the tenth pair. At its cranial end this same nerve is found to be in direct relation with the trigeminus through the intervention of the gray tubercle of Rolando. This fact undoubtedly furnishes the key to the headache which so often accompanies gastralgia.

The vagus is the chief sensory carrier of the reflex movements of circulation and respiration. Thus, irritation of the renal and hepatic plexuses can produce vomiting.

Angina pectoris has its seat in the cardiac plexus. The sensation experienced is like that seen in the renal and hepatic plexuses after renal and hepatic colic.

ELEVENTH PAIR, OR SPINAL ACCESSORY NERVE.

The eleventh pair of cranial nerves, the spinal accessory, is composed of two distinct parts: a *spinal* portion and an *accessory* portion. A group of cells in the anterior horns of the spinal cord and extending downward to the sixth cervical segment is called the accessory nucleus. There is another group of cells at the exit of the first cervical nerve which extends into the medulla oblongata and is the origin of the hypoglossal nerve. The medulla-oblongata root arises from the nucleus ambiguus, which is connected with the vagus nucleus in the medulla.

The *superficial origin* of the accessory portion is from the groove between the inferior olive and the restiform body. Near the jugular foramen both portions come together, but do not exchange fibers. Very soon both roots separate from one another to form the two distinct branches.

The *accessory portion* of the nerve passes entirely into the plexus gangliformis of the vagus. This branch supplies the vagus with the major portion of its motor fibers.

The spinal portion enters the cavity of the cranium by passing through the foramen magnum. The two portions of the spinal accessory leave the cranium together by passing through the middle compartment of the jugular foramen. The spinal portion then pierces the sterno-mastoid to supply it and the trapezius. This portion of the nerve communicates with several cervical nerves.

Physiology.—The eleventh nerve is generally considered to be motor. Any observable sensibility must be due to anastomosis with the cervical nerves.

From experimentation it has been found that the accessory branch presides, through motor branches in the vagus to the laryngeal muscles, over the *formation* of sound and its tone. The spinal branch is concerned in the duration, intensity, and modulation of the vocal sound. Hence it regulates the rhythm of speech and song.

Aphonia is often due to hysteria, but may be due to lead-poisoning, syphilis, or to such reflex causes as intestinal worms. The reflex that is established between the vocal and genital organs is also shown by troubles in the spinal branch of the spinal accessory. The voice may be lost at times during menstruation.

TWELFTH PAIR, OR HYPOGLOSSAL NERVE.

The nuclei of the hypoglossal nerve are under the floor of the fourth ventricle, on each side of the raphé. Beneath the main nucleus of the hypoglossal nerve is a collection of cells in the formatio reticularis, called the hypoglossal nucleus of Roller.

Cortical Connection.—The motor path is from the inferior part of the central convolutions.

Anastomoses.—The connections of the hypoglossal are: 1. With the superior cervical ganglion of the sympathetic, which supplies vasomotor fibers to the vessels of the tongue. 2. The plexus gangliformis vagi gives a small lingual branch which supplies the tongue with sensory fibers. 3. The hypoglossal is also connected with the upper cervical nerves.

Physiology.—The hypoglossus, by itself, is purely motor. It moves the muscles of the tongue. When its original filaments are torn out there is never any pain. Sensibility of its terminal branches is due to anastomoses with the lingual. When the hypoglossus is cut, the tongue remains quiescent in the mouth.

In unilateral paralysis of the hypoglossus the tongue, when protruded, passes over to the *paralyzed side.* This phenomenon is occasioned by the action of the genio-hyo-glossus of the sound side.

LITERATURE CONSULTED.

Gordinier, "Nervous System."

CHAPTER XXI.

REPRODUCTION.

ALL physiological phenomena described in the previous chapters have as their ultimate result the maintenance of the life of the individual itself. No matter, however, with what regularity these physiological processes are taking place, the life-period of a given animal is not of an unlimited duration. Sooner or later the more or less complicated mechanism stops its activity, and the individual ceases to exist. With its death, not only all traces of the former existence of the individual, but also, with it, the existence of the entire species to which the individual belonged, would be entirely wiped out, had nature not provided for a process of *rejuvenation*, as it were, of all living beings. This very important and peculiar phenomenon in the economy of all living organisms, animal as well as plant, is generally known as the process of Reproduction, the ultimate aim of which is to maintain the species. We have to confine ourselves to a consideration of animal reproduction only, and, even here, we find this important process carried out in various ways. In lower animals, in which a specialization of different parts of the body to different functions is not yet established, the process of reproduction is also more or less simple. The body of an amœba becomes constricted and finally is divided in two halves, and each of these halves becomes a fully developed animal, capable of multiplying in the same fashion. A portion of a hydra, separated from the living animal, is capable of developing into a complete new hydra. This method of reproduction is called *non-sexual.*

Throughout the greatest part of the animal kingdom, where we find well-defined physiological division of labor in regard to other vital functions, we also find the function of laying the foundation for perpetuating the species assigned to special parts—*organs of reproduction.* The product of these specialized organs is known in modern biology as the *germ-plasm*, and it is upon this structure that the formation of a new individual and the transmission of all the qualities from the parents to the offspring—the *heredity*—are considered to depend. The starting point for the development of every individual we find represented in a typical cell, called an *ovum*, containing the germ-plasm, and therefore also called *germinal cell.*

There are a few instances, however, in which the ovum alone is capable of reproducing a new individual. This is observed only among lower animals, and this method of reproduction is known as *parthenogenesis.* In all more highly organized animals the ovum is not capable of developing into a new individual, unless it comes in contact and fuses with a part of another germinal cell called a *spermatozoön.* This method is called *sexual reproduction.* In it the ovum presents the female element, the spermatozoön the male element of reproduction. The process of meeting and ultimate fusion of the two elements to form one, capable of forming a new individual, is called *fertilization.*

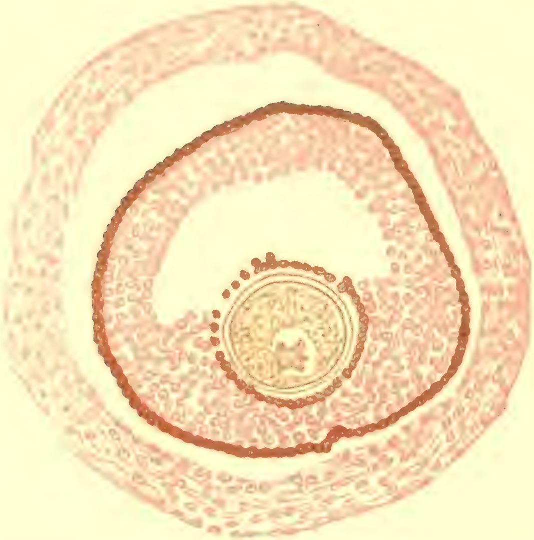

Fig. 378.—Graafian Follicle from Ovary of a New-born Child. (After P. Strassman.)

It consists of five portions: (1) An external membrane or zona pellucida. (2) An internal membrane or vitelline membrane which lies in close to the yelk; between the two membranes is a slight space, the peri-vitelline space. (3) The yelk or vitellus, containing yelk grains or dentoplasm. (4) The nucleus, germinal vesicle, vesicle of Purkinje. (5) The nucleolus, germinal spot, spot of Wagner, consisting mainly of chromatin.

The fact that in producing a new individual a union of male and female elements takes place has been known for centuries; but in regard to the importance, or the predominating influence, of the one or the other of these elements, the views have changed. During the eighteenth and part of the nineteenth centuries, we find among investigators and interpreters of this phenomenon two extreme views represented. Some investigators considered the spermatozoön as a very minute but complete animal—*animalculus*—containing all the organs of its parent animal *en miniature.* By means of a slender tail they were supposed to move around until they found an appropriate soil—the ovum—to which they became attached and from which they received the necessary stimulus to grow, and gradually attained the size characteristic to the type. The advocates of this view have been known as *animalculists.*

The advocates of the other, extremely opposite, view—the *ovists*—considered the ovum to be like the bud of the plant, containing all the parts of the future animal wrapped together, and, being met by the spermatozoön, the parts received a stimulus for their unfolding and growth until the typical size has been reached. It is obvious that these both extreme views are based on a common supposition that either the spermatozoön or the ovum represents an already preformed organism, and therefore both of these views have accordingly been known as the *theory of preformation.* A detailed account of other theories on this subject is generally given in text-books of embryology. For the understanding of the physiology of reproduction, it suffices to state that subsequent investigations have proven conclusively that the ovum as well as the spermatozoön represent but *single cells.* Simultaneously with the astonishing facts, revealed during the last few decades, of the structure and life-history of the cell in general, which are presented in the first chapter of this book, very much light has been thrown on the structure and life-history of the cellular elements specialized for reproduction. According to the facts known at the present time, it is pretty well established that both the spermatozoön and the ovum originate from the same source, the *germinal epithelium;* both undergo a preliminary process of ripening, *maturation,* before they are able to participate in *fertilization;* and, while the rôle assigned to one of them in the latter process is not exactly the same as the rôle assigned to the other, they are nevertheless *equivalents* in regard to their ultimate significance for the process of producing a new individual.

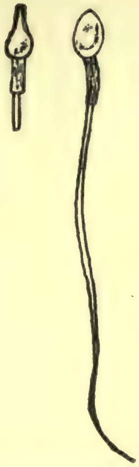

Fig. 379.—Human Spermatozoön. (MANTON.)

To fully appreciate the different stages of the process of reproduction mentioned above, a brief account of the origin, formation, and structure of the ovum and spermatozoön is essential.

The beginning of the differentiation of the organs of the animal body from the blastoderm, of which we will speak later, we find expressed in the arrangement of the building material, so to speak, in three distinct so-called germinal layers—an outer layer, the ectoderm; an inner one, the entoderm; and between these two a middle layer, the mesoderm. The first two layers we find very well defined in all Metazoa, and from them all vital organs of the body, composed of epithelium, are developed. The middle layer supplies the supporting and connective tissues and the vascular system. In the lower types of Metazoa, which require very little supporting material, and in which a special vascular system is not present, we find also the mesoderm very scantily presented. The higher the type of the animal, the more we find the mesoderm developed, until we finally see it not only as a well-defined single layer, but it becomes split into two secondary layers: one, the *parietal mesoderm,* which follows and gives support, and supplies blood-vessels and nerves to the ectoderm and its derivatives, and a second one, the *visceral mesoderm,* which acts in the same way for the entoderm. The space formed between them constitutes the future body cavity or cœlom. It is in this middle layer where we find the first traces of the two kinds of the elements of reproduction—the spermatozoa and ova. In the lower types, with scanty mesoderm, we find these elements loosely scattered within it; in the higher types, with well-defined, double-layered mesoderm, we find certain parts of it crystallized, so to say, as organs of reproduction—the ovaries and testicles. It was Waldeyer who first called attention to the fact that a certain part on the visceral layer of the mesoderm becomes thickened and forms the so-called *genital ridge,* which gives rise to the organs of the primitive genito-urinary apparatus. A part of the ridge-cells be-

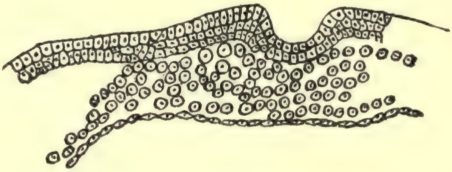

Fig. 380.—Transection of Chick Embryo, Showing the Three Plastodermic Layers. (MANTON.)

comes the above-mentioned *germinal epithelium* of Waldeyer, because it is these cells which, by their down-growth into the subjacent layers, gradually become transformed, first, into indifferent sexual cells, and, ultimately, into *spermatozoa* or *ova*, as the case may be. Leaving out the detailed account of the development of the testicle and ovary, to be found in text-books on embryology, we have to consider the formation of the spermatozoa and ova as it takes place in a fully developed ovary or testicle. In the seminiferous tubules of the testicle we find five physiologically different kinds of cells. Covering the inner surface of the basement membrane of the tubule we find the so-called layer of *parietal cells*, consisting of two kinds of cells, of a different physiological character: (1) the sustentacular, and (2) the spermatogenic cells. Both kinds undergo karyokinetic multiplication, but the fate of their offspring is different. Each offspring of a sustentacular cell, after attaining its full size, is not only morphologically, but also physiologically, fully equivalent to the parent cell, as it is ready to serve its ultimate definite purpose—supporting and generally uniting with other cells of its kind, it forms stronger

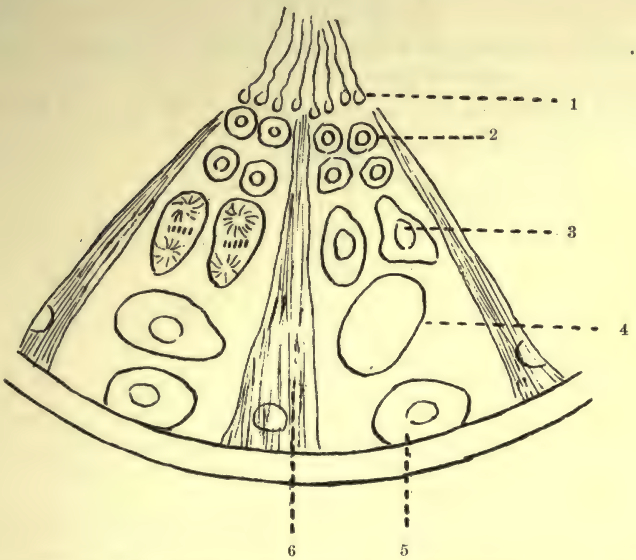

Fig. 381.—Diagram Showing Development of Spermatozoa in a Seminal Tubule. (McMurrich.)

1, Spermatozoön. 2, Spermatid. 3, Secondary spermatocyte. 4, Primary spermatocyte. 5, Spermatogone. 6, Supporting cell.

supporting units, the so-called columns of Sertoli. In regard to the spermatogenic cells, we see an entirely different state of affairs. The function of each spermatogenic cell is nothing else but to undergo karyokinesis and form two cells, called mother-cells. Each mother-cell performs the similar function and gives rise to two other cells, called daughter-cells; but these cells differ from their two consecutive predecessors. They do not multiply further, but in the

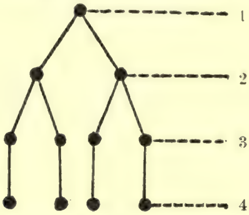

Fig. 382.—Schema to Indicate the Process of Maturation of the Spermatozoa. (Boveri.) (Howell.)

1, Primary spermatocytes. 2, Secondary spermatocytes. 3, Spermatids. 4, Spermatozoa.

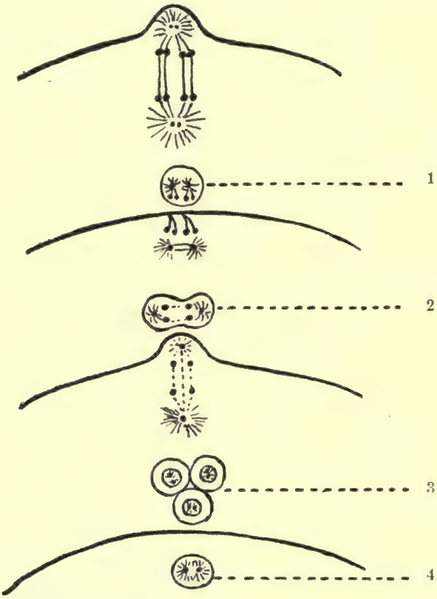

Fig. 383.—Diagram Showing Essential Facts in the Maturation of the Egg. (Wilson.)

1, First polar body. 2, Division of first polar body. 3, Three polar bodies. 4, Female pronucleus.

material constituting their structure a rearrangement takes place, and gradually each of these daughter-cells becomes transformed into a spermatozoön, with its characteristic parts: the head, middle piece, and tail. It is evident, therefore, that each spermatogenic cell gives rise to four spermatozoa, all equally qualified to take part in the physiological process assigned to them—fertilization. This is diagramatically represented in the figure of Boveri (Fig. 382).

In the ovary we find the Graafian follicle, containing two different kinds of cells: one large one, the ovarian ovum, corresponding to the spermatogenic cell of the testicle; and more numerous smaller ones, supporting or protecting the larger by forming a capsule, as it were, around it and constituting the *membrana granulosa* with its *discus proligerus*. Like the spermatogenic cell, the ovarian ovum also undergoes the karyokinetic division, but with somewhat different result. We find two cells formed, one of which is very large and contains the chromatin substance and the cytoplasm in the same proportion as the egg cell, and another, which is very small and contains only chromatin, and little cytoplasm. A second division of the larger cell takes place, with the same result, forming again one large cell and one very small one. The first small cell, in the meantime, frequently also divides in two, and, because the three small cells are found grouped together on one of the poles of the large cell, they received the name *polar bodies*. They take no part in the processes following, and gradually disappear. The large remaining cell is the *mature ovum*, the one which is qualified for fertilization, and the series of changes through which the ovarian ovum has to pass to become so qualified is called maturation. The parallelism in the changes which take place during formation of the two sexual

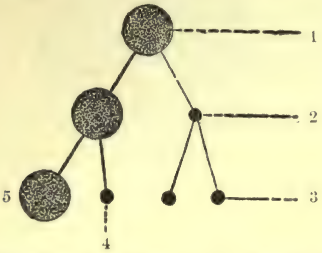

Fig. 384.—Schema to Indicate Process of Maturation of Ovum. (Boveri.) (Howell.)

1, Ovarian egg. 2, First polar body. 3, Abortive ova resulting from division of first polar body. 4, Second polar body, abortive ovum. 5, Mature egg.

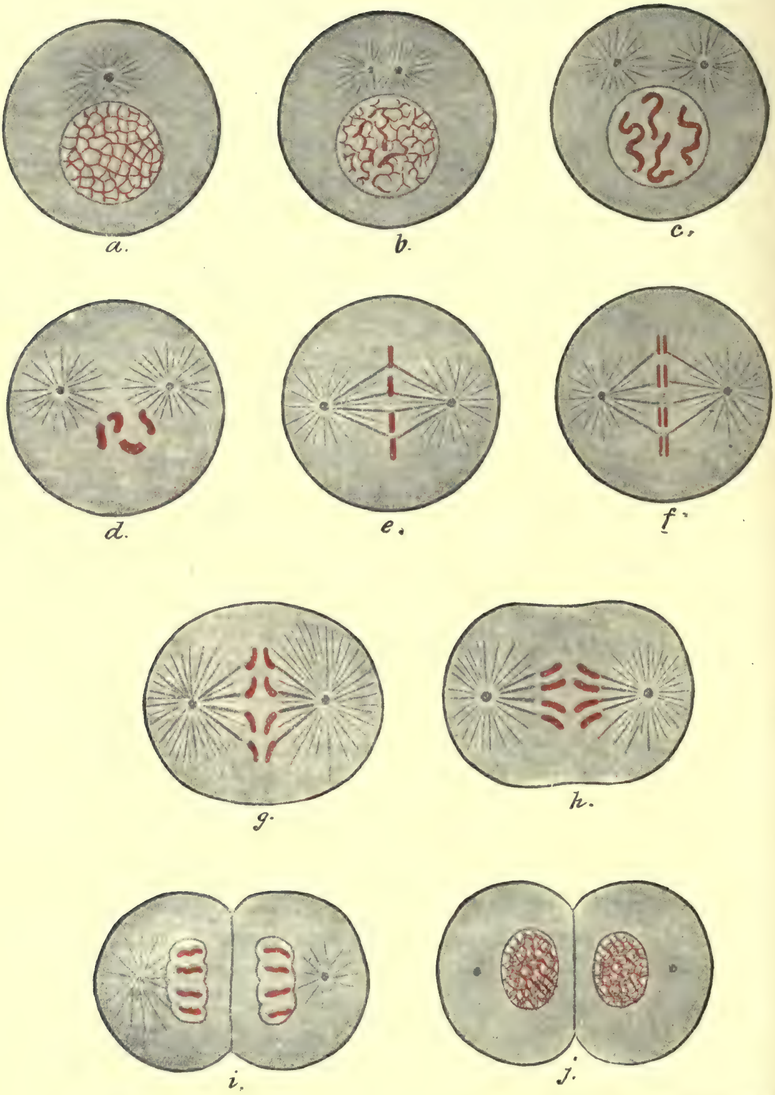

Fig. 385.—Schematic Representation of the Processes Occurring During Cell-division. (Boveri.) (Howell.)

cells are very lucidly represented by Boveri in the two schematic figures (Figs. 382 and 384).

The process of maturation is also called *reduction division,* because it is known at present that the quantity of chromatin substance in the nucleus of either of the sexual cells, or the number of chromosomes which the chromatin thread forms, is reduced to one-half of the quantity typical to all other cells of the same animal. In regard to other essential parts, we find the spermatozoön containing only very little cytoplasm, while the mature ovum contains nearly all the cytoplasm of the original ovarian ovum. The centrosome is considered by Boveri to become lost in the ovum, while in the spermatozoön it is retained, and later plays an important part. The process of *fertilization* itself consists in a union of the male with the female element to form one capable of being the foundation for a new individual, although in regard to the details of this process the facts known at present, and the interpretations given, can by no means be considered conclusive. A very widely and favorably accepted view is presented by Boveri in *a* to *g* (Fig. 386), and the essential points are the following: either attracted by chemotaxic force radiating from the ovum, or by their own locomotion, the spermatozoa come in contact with the ovum and pierce the zona radiata; but as soon as one spermatozoön penetrates into the cytoplasm of the ovum, a reaction on its surface takes place, making it impermeable for other spermatozoa. During its entrance into the ovum, the spermatozoön usually loses the tail, while the head, which in reality represents the chromatin substance of the nucleus, becomes expanded, takes on the character of a nucleus, and moves towards the nucleus of the ovum. The egg at this stage obviously contains two nuclei; the one is called *male pronucleus,* and the other *female pronucleus.* Gradually both come in contact and form the so-called *segmentation nucleus.* The middle piece of the spermatozoön also enters the ovum. Soon, however, it reveals itself as a centrosome and acts as a dynamic force for a cleavage of the segmentation nucleus, which inaugurates the process of cell-division. With this first cleavage the formation of a new individual has actually begun. Through successive cell-divisions an aggregation of cells is finally formed, which, depending on the amount of nutritive material stored up in the ovum for future purposes, becomes arranged either in form of a spherical mass (morula), which gradually becomes hollow and is then called a *blastula,* or as a *circular disk,* and in either case a uniform layer of cells is gradually formed, which is known as the *blastoderm.*

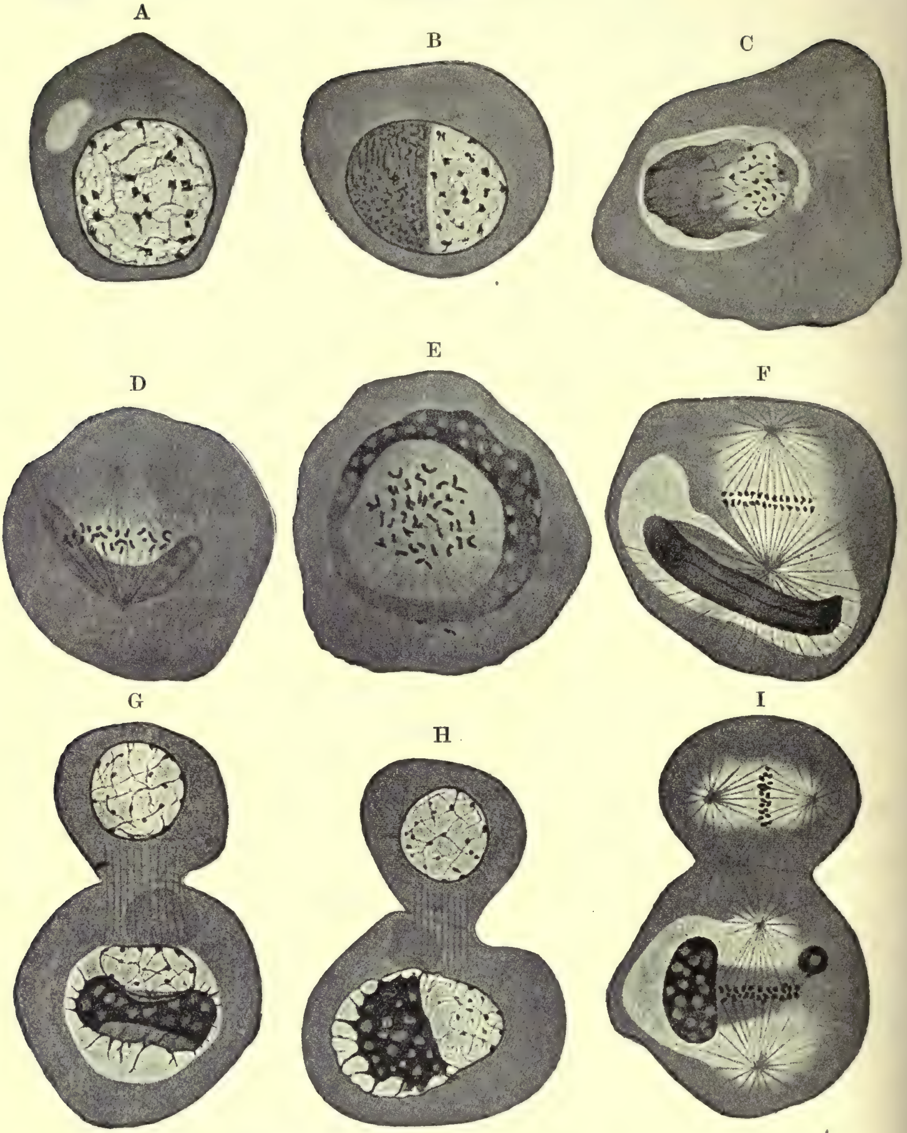

Fig. 385*a*.—Differentiation of the Germ Cells and the Somatic Cells During Oögenesis in Dytiscus. (After GIARDINA, 37.)

(Fig. *I* is a reconstruction from the author's various illustrations). Fig. *A*, oogonia O_1 in preparation for division. Fig. *B*, The same in a somewhat later stage; separation of the isolated chromosomes from a continuous reticular mass of chromatin. Fig. *C*, Dissolution of the nucleus; the chromosomes enter the spindle, while the remaining chromatin undergoes transformation and forms a compact ring-like body situated around the spindle, as represented in Fig. *D* in side view and in Fig. *E* in polar view. Fig. *F* presents the moving away of the ring-like body outside of one of the poles of the spindle. It thus becomes incorporated exclusively with the lower one of the daughter cells, oogonia O_2 as presented in Fig. *G*. Fig. *H* presents the resting nucleus of the oogonia O_2 formed by the chromosomes and externally united with the ring-like body, which has also acquired the nuclear shape. When O_2 is preparing for the process of division, the same separation of the constituents becomes visible (Fig. *I*.) (BOVERI.)

Through invagination of the blastula, forming the cup-shaped *gastrula,* or through delamination from the disklike layer of cells, a blastoderm is gradually formed, which consists of two distinct layers, an outer one, called *ectoderm,* and an inner one, called *entoderm.*

The next step of advancement in the development is one to which the attention of all distinguished embryologists has been kept engaged for many decades. It is the gradual formation of a distinct third layer of cells between the outer two, which is called the middle layer, or *mesoderm.* Some investigators have proved that in certain animals the mesoderm originates from the entoderm; others, again, have shown that it takes its origin from the ectoderm. The present state of our knowledge leads us to assume that from the morphological point of view throughout the animal kingdom both modes of origin can be found to take place. The far more important physiological aspect and significance of the question is closely correlated with the broader questions of general biology, and to them we will turn our attention now.

With the differentiation of blastoderms into three distinct, so-called germinal layers, the foundation for a physiological division of labor is established and the formation of the various organs—organogenesis—begins. A description of the details of it, however, are beyond the scope of this text-book. Here it is only necessary to emphasize the important fact that each of the three layers represents not only a morphological, but also a physiological, unit, as each one of them gives rise only to certain tissues and organs of the adult, and neither one can be substituted in that respect by another without producing abnormal conditions. This fact is of such great principal significance that pathologists have adopted a classification of tumors according to the three germinal layers and their derivates.

An exceedingly important, as well as interesting, question which occupies the minds of modern biologists is whether the physiological differentiation of the germinal layers begins only with the formation of these structural units, or whether it is already present at an earlier stage of the development of the ovum, and becomes more perceivable only in the germinal layers. The attempt to answer this question leads us over to the consideration of the vital problems in general biology—evolution and inheritance—which I will shortly take up.*

It has been shown by Loeb that the unfertilized egg of the sea

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* The preceding pages upon reproduction have been contributed by Dr. P. Fischelis.

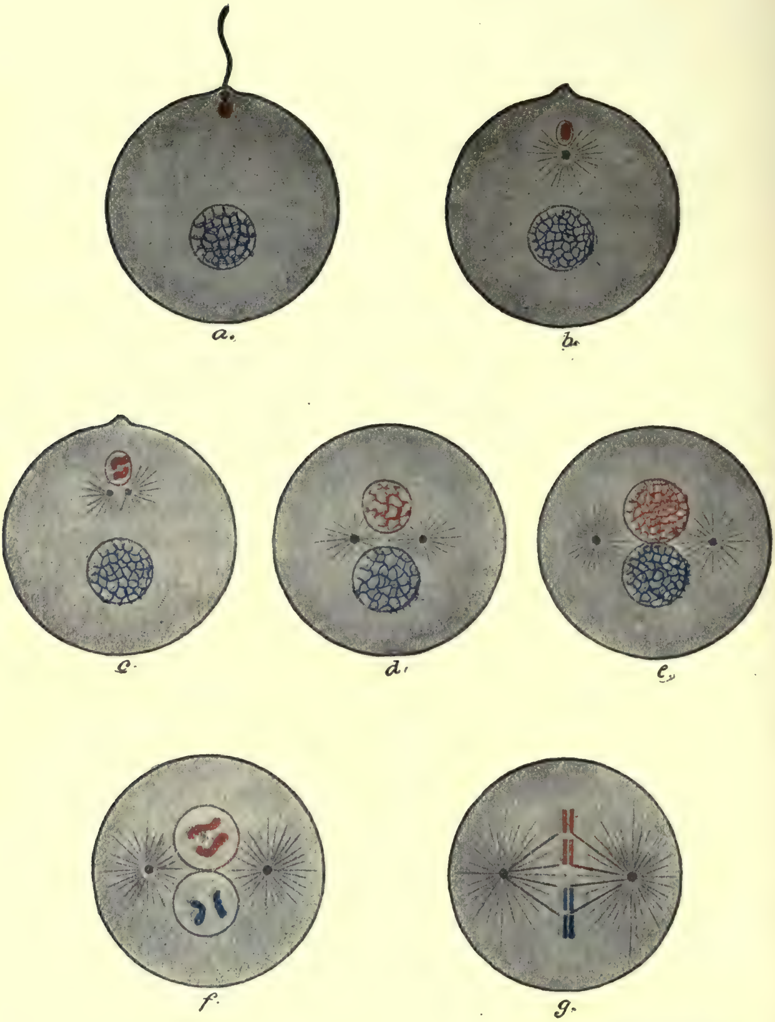

Fig. 386.—Schematic Representation of the Processes Occurring During the Fertilization and Subsequent Segmentation of the Ovum. The chromatin (chromosomes) of the ovum is represented in blue, that of the spermatozoön in red. (Boveri.) (Howell.)

urchin can develop by chemical agents without spermatozoa. He treats the egg for a minute or more with acetic acid, to cause a membrane to form around it. They are then deposited in a hypertonic sea-water, made by the addition of sodium chloride to ordinary sea-water. Afterwards they are transferred to ordinary sea-water, and soon they multiply and develop into normal larvæ. Loeb believes that the unfertilized egg of the sea urchin possesses all the elements for development, and the only reason parthenogenesis in it is prevented is the constitution of the sea-water. Here the process is mainly ionic. He believes that the nucleus of the spermatozoön is not essential, and that it is only a means to stimulate the arrangement of ions surrounding it.

How does the ovum arrive in the uterus? There is considerable obscurity on this point. Most observers believe the ovum is discharged into the pelvic cavity, where the cilia of the Fallopian tube propel it toward the uterus. It is in the tube that the spermatozoön meets the ovum, which here undergoes fecundation, arrives in the uterus, and develops. The spermatozoön is deposited in the vagina or at the mouth of the uterus, and, by means of its cilium or tail, travels up the uterus and Fallopian tube.

Should the ovum not be impregnated, it dies and passes out of the uterus as a constituent of its secretions. On the other hand, should it become fecundated, the ovum becomes attached to the mucous membrane of the uterus, usually occupying the bottom of some little cleft or pouch.

The investigations of Peters, of Vienna, and of Webster, of Chicago, show that the uterine mucosa does not fold up around the ovum, but that the mucosa at the site of implantation is eroded; so that the ovum eats its way, as it were, into the mucosa, sinking into its depths until the edge of the swollen mucosa closes over it, thus forming the decidua reflexa.

The position to which the fecundated egg becomes attached is the decidua serotina, and it eventually forms the placenta, the nutrient organ of the embryo. Before the ovum arrives in the uterus it has formed the amnion and chorion with the villi of the chorion. Some of the ectodermal cells in the chorion become specialized to form what is called the trophoblast, and this probably transfers nourishment from the mother to the ovum.

After its formation the mesoderm grows by reason of its own cell-proliferation, and is independent of its dual source. Along either side of the median line the mesoderm presents a thickening of cells (vertebral plate), which becomes laminated laterally (lateral plate). From the vertebral plate develop the *somites;* the lateral plate splits into two lamellæ, of which the outer is the *somatic mesoderm;* the inner, the *splanchnic mesoderm.*

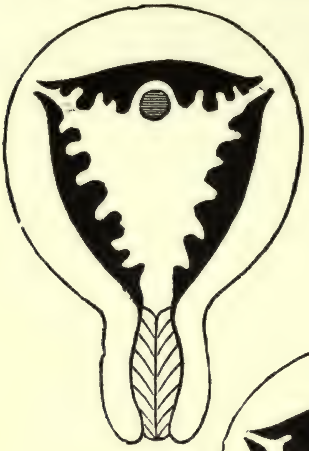

Fig. 387.

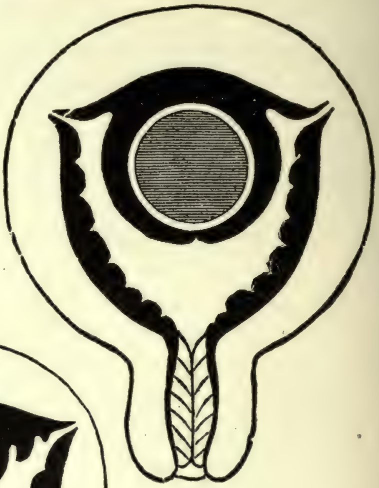

Fig. 389.

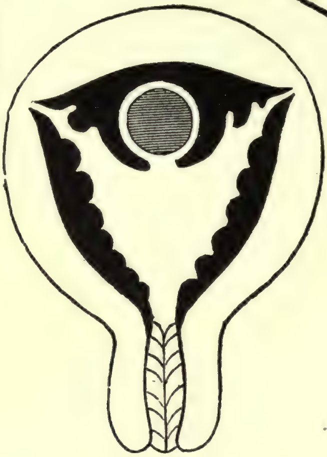

Fig. 388.

Fig. 387.—Formation of Decidua (the decidua is colored black, the ovum is represented as engaged between two projecting folds of membrane). (After Dalton.)

Fig. 388.—Projecting Folds of Membrane Growing Around the Ovum. (After Dalton.)

Fig. 389.—Showing Ovum Completely Surrounded by the Decidua Reflexa. (After Dalton.)

The former unites with the ectoderm to form the *somatopleure,* while the latter unites with the entoderm to form the *splanchnopleure.* Between the somatopleure and the splanchnopleure there is an opening, the *body-cavity,* from which arise the serous cavities of the adult.

Derivatives from the Layers.

Ectoderm, or Epiblast.—From the epiblast are developed the central nervous system and the epidermal tissues.

Mesoderm, or Mesoblast.—From the mesoblast arise most of the organs of the body. These include the vascular, muscular, and skeletal systems; also the generative and excretory organs; but not the bladder, the first part of the male urethra, nor the female urethra.

Entoderm, or Hypoblast.—The hypoblast is the secretory layer. From it spring the intestinal epithelium and that of the glands which open into the intestines; also the epithelum of the resipratory system, the bladder, the prostatic part of the male urethra, and the entire female urethra.

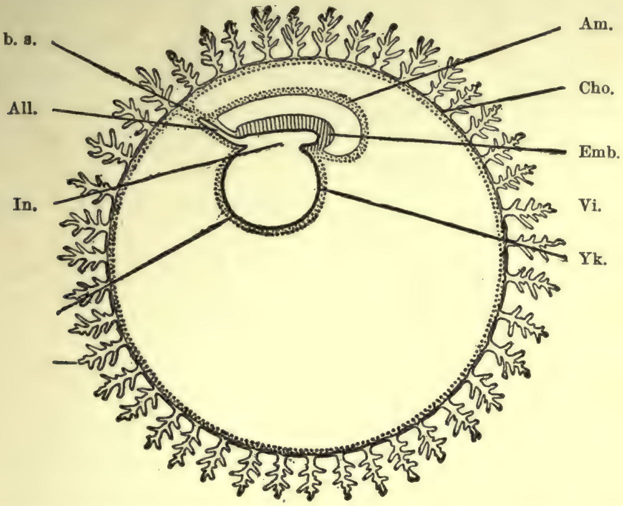

Fig. 390.—Diagram of an Early Stage of a Primate Embryo. (Minot.)

All, Allantois. *Am,* Amnion. *b.s.,* Body-stalk. *Cho,* Chorion. *Emb,* Embryo. *In,* Entodermal Cavity of Embryo. *vi,* Villi of Chorion. *yk,* Yelk-sac.

Up to this point the cavity of the germ is one undivided compartment bounded by splanchnopleure. By infolding of the splanchnopleure this cavity is divided into two smaller compartments of unequal size. The smaller is the *gut-tract;* the larger, the *yelk-sac,* or *umbilical vesicle.* The communication between the two cavities is the *vitelline duct.*

With the unfolding of the splanchnopleure the somatopleure also follows, to form the body-walls of the embryo. Part of the somatopleure becomes so lifted up as eventually to curl up and over the embryo until the fold of one side fuses with that of the other. That is, there is formed the amniotic membrane and cavity. The amnion is a membranous sac consisting of two layers of embryonal cells. The inner layer is composed of ectodermic cells, the outer layer of mesodermic cells. The false amnion, or serosa, comprises all that part of the somatopleure which does not go to form the body-wall and the true amnion. It is also called the primitive chorion and by some authors the chorion. The allantois growing forth from the gut-tract unites with its inner surface and thus gives it vascularity. It is the outermost envelope of the germ. The amniotic sac is filled with a fluid in which floats the fœtus.

The function of the *yelk-sac* is to furnish nutrition to the embryo for a certain length of time, but is very rudimentary in man. As the yelk-sac disappears by degrees, its place is taken by the *allantois*. The latter then serves as a medium of nutrition and respiration until the formation of the placenta at the end of the third month.

Chorion.—The chorion is the membrane which envelops the ovum subsequent to the appearance of the amnion. It results from the fusion of the allantois and false amnion.

Upon the surface of the chorion are numerous *villi*. At first they are uniform in size, but at the latter half of the first month there develops an area the villi of which are noted for their long prolongations: the *chorion frondosum*. This eventually becomes a portion of the placenta. The remaining villi atrophy and finally disappear.

Chemical Constituents of Spermatozoa.—In the head of the spermatozoa of salmon of the Rhine is found a chemical body which is a combination of nucleic acid and a protamin. In different fishes the protamin is given a different name. Thus, we have scrombrin from scromber scrombrius, salmin from salmon, clupein from herring (clupea harengus), sturin from sturgeon (accipenser sturo). The protamins are strong bases and their watery alkaline solutions are intensely akaline, and with acids they form characteristic salts. They all give the biuret reaction, and, it is to be noted, without the addition of an alkali. Protamins are not coagulated by heat, and polarize to the left. These peculiarities place the protamins in a class peculiar to themselves. Clupein, chemically, is identical, according to Kossel, with salmin.

A peculiarity of the protamins is the high percentage of nitrogen; in salmon it forms nearly a third of the whole weight. By breaking up the protamins by acids it was found that the chief element in the protamins is arginin, with the hexone bases. In the semen of the carp (cyprinus carpio) Miescher obtained no protamin, but a "peptonelike" substance with basic properties which is a histon, which makes bases very easily with acids. The histon possesses the usual properties of the albumins.

The nucleo-proteids in the heads of all spermatozoa are a nucleic acid compound. The nucleic acids of sperm are organic phosphoric acid combinations. The protamins and histon have been found only in the semen of some fishes, and not in that of mammals.—Burian—Asher und Spiro's Ergebnisse der Physiologie, Part I, 1904.

Erection.—The erectile tissue of the male is formed by the penis, formed of corpora cavernosa and the corpus spongiosum. During erection the penis is gorged with blood, due to the arterioles, which are supplied by vasodilator nerves in the nervus erigens. Besides the vasodilation, the return flow of blood by the dorsal vein is partially arrested by the muscle of Houston. The smooth muscles of the trabeculæ also aid in the act of erection. Erection is a reflex phenomenon, and the center is located in the lumbar cord. The sensory nerve concerned is the pudic, for Eckhard found that section of this prevented, in the dog, any erection when the glans penis was irritated. Other irritations, as of the testes or the prostatic urethra, lead to erection. A full bladder in the morning is also frequently accompanied by a passive erection, due to a compression of the venous plexus of Santorini by the bladder. The genito-spinal center in the lumbar region is also affected by impulses coming from the brain, which may be of two kinds, excitatory and inhibitory. The penis also receives vasoconstrictor fibers, which emanate from the second to fifth lumbar nerves, and reach the penis either by the pudic or the hypogastric plexus. The surface of the organ, its integument, usually slightly folded, becomes tense, and the engorged subcutaneous veins are seen beneath the surface. During erection the clonic contraction of the bulbo-cavernous muscle pushes the blood towards the glans. These muscles are aided in a similar manner by the ischio-cavernous muscles. These two muscles have been compared to peripheral hearts in the vascular movement of this organ. In disease of the spinal cord erection is often lost or suppressed, so that coitus is impossible.

Ejaculation of Semen.—At the moment of erection the urethral canal becomes filled with a secretion of its different glands.

All these glands and the seminal vesicles furnish a liquid capable of diluting and liquefying the semi-solid semen as it leaves the vas deferens. The smooth muscles of the vasa deferentia, vesiculæ seminales, aided by the dartos and cremaster muscles, which compress the testicles, make semen accumulate in the urethra between the congested verumontanum (which prevents its regurgitation into the bladder) and the urethral sphincter.

The friction of the glans is the cause of the ejaculation. This friction, in a reflex manner, causes the involuntary and spasmodic contraction of the vas deferens and of the seminal vesicles.

The escape of semen in jets is due to the rhythmic contraction of the bulbo-cavernous and ischio-cavernous muscles, aided by the other muscles of the perineum. Ejaculation is accompanied by a general excitement of the brain. However, Goltz has shown that after a transverse section of the cord in the dog, ejaculation can still ensue.

Castration.—In castrating a bull or a guinea-pig it is found that the thymus is greatly retarded in its stage of atrophy, so that the thymus of an ox exceeds considerably that of a bull. The testes greatly increase in size in guinea-pigs after removal of the thymus. Hence it is probable that the thymus has an internal secretion which controls the growth of the testicles.

Prostate.—The secretory nerve of the prostate gland is the descending branch of the inferior mesenteric ganglion. The vasodilator fibers of the prostate are contained in the nervus erigens and its two branches. The vasodilation of erection is accompanied by a vasodilation in the prostate. When atropin is given, irritation of the secretory nerves of the prostate is without effect. Pilocarpin increases the secretion.

Menstruation.—In the adult female during certain age-limits there occurs a discharge from the genitalia once about every twenty-eight days. This periodical discharge consists of blood, dead and disintegrated epithelium from the uterus, and mucus from the glands of the uterus.

With the discharge of the above-named materials there is *usually* expelled at the same time one or more ova from their follicles. However, ovulation and menstruation may be, and very often are, independent of one another. The onset of menstruation is usually heralded and then accompanied by certain constitutional signs of fullness and pain in the pelvic region. There is a real congestion of all of the pelvic organs; in particular the uterine mucous membrane is swollen and congested. From it are derived the blood and epithelium of the menstrual flux. By some authorities it is claimed that the entire uterine mucous membrane is exfoliated at every flux, to be regenerated in the *interim*.

It has been found by observers that congestion of the ovary coincident with sexual intercourse is capable of rupturing Graafian follicles and so liberating ova. From this it is reasonable to suppose that the congestion and high tension of the generative organs during the time of menstruation would surely accomplish the same end.

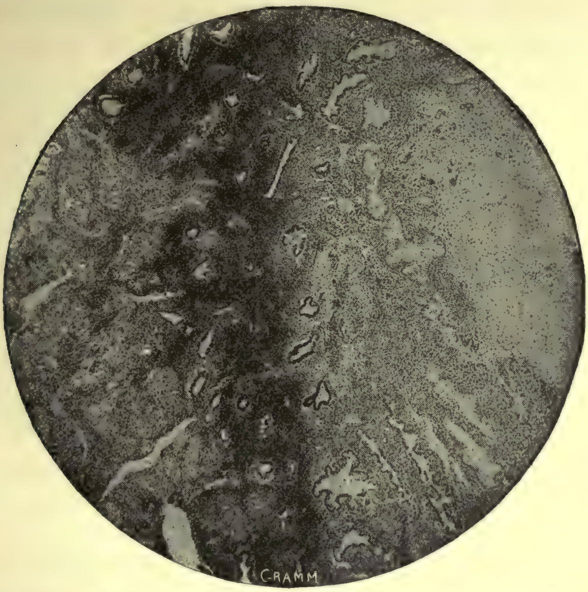

Fig. 391.—Uterus at Menstrual Period, Showing Congested Area and Destruction of Mucous Membrane. (Photomicrograph by Gramm.) (Gilliam.)

The usual period of a female's life during which she menstruates is from *puberty* (from the thirteenth to the fifteenth year) to the *climacteric,* or *menopause* (about the forty-fifth year). Its cessation at the latter period denotes the end of the childbearing period.

The cessation of menstruation may be abrupt or gradual, and is frequently accompanied by disturbance of the physical and the mental functions. Removal of the ovaries usually causes menstruation to cease; occasionally, however, menstruation persists. If after the ovaries are removed and menstruation has ceased, an ovary is transplanted, then menstruation returns.

THEORY OF MENSTRUATION.—There are two theories. In Pflueger's theory, the discharge of blood is looked upon as a physiological freshening of the tissue, like in surgery, for the reception of the ovum and its union with the mucous membrane.

In Reichert's theory, before the discharge of the ovum a change takes place in the uterine mucous membrane, which becomes swollen up, more spongy, more vascular, and more ready to nourish an impregnated ovum. If the ovum is not impregnated, then there is degeneration of the uterine mucous membrane, and a flow of blood ensues.

Both theories believe that menstruation is a preparation of the uterine mucous membrane for the reception of the ovum.

It is usually recognized that ovulation is arrested during pregnancy and lactation. The amount of menstrual blood is usually about $4^1/_2$ ounces, and the flow generally lasts four days.

Marshall and Jolly have shown that ovulation cannot be the cause of either heat in animals or menstruation. They show that the whole procestrous process is of the nature of a preparation for the attachment of the embryo to the uterine mucous membrane. The ovary of a mammal elaborates an internal secretion which, at recurring periods, is the cause of the procestrous and the œstrous. The corpora lutea form a ductless gland, which is necessary for the nutrition of the trophoblast during the early stages of pregnancy, and subsequently atrophies.

Bond believes the endometrium has a saline secretion peculiar to the anœstrous state; that some substance is elaborated by the pregnant uterus which stimulates the growth of the corpora lutea in transplanted ovaries. He believes the ovary furnishes a secretion having an anabolic influence on the uterus and produces the œstrus. The saline uterine secretion is antagonistic to the action of the ovarian secretion.

Corpus Luteum.—The place in the ovary where the bursting of a Graafian follicle by the overdistension of the liquor folliculi ensues is usually filled up with what is known as the corpus luteum. The follicle collapses, and in its interior remains a lining of granulosa cells and a clot of blood. Cells of the corpus luteum, containing a yellow body (lutein), are formed from a proliferation of the internal connective-tissue cells. If pregnancy ensues, the true corpus luteum is larger, thicker, and deeper in color than the false corpus luteum of menstruation.

Pregnancy.—With the impregnation of the ovum pregnancy begins. Menstruation is arrested, and nausea or morning sickness ensues. At the end of the second month the nipple swells, becomes more erect, and projects forward. Then the areola of the nipple enlarges, becomes puffy, and deepens in color. Toward the fifth month the mammary glands increase in size. As to the genitals, the mucous membrane of the vagina becomes of a violet hue, the vaginal part of the cervix grows softer, a peculiar velvety softness at the end of the third month. At the end of the third month the uterus is the size of a fœtal head, of certain doughy, elastic feel. About the sixteenth week active spontaneous fœtal movements are felt, popularly known as "quickening." From the eighteenth week up to the end of pregnancy the fœtal heart-sounds are heard, which vary from 120 to 160 per minute. During the last three months the uterus becomes more distended, its walls are more muscular and vascular. After a period of 280 days of gestation labor begins, and the contents of the uterus are expelled. At birth the ligature of the umbilical cord cuts off the placental circulation. The placenta, being now a foreign body in the uterus, is expelled. The ruptured and opened vessels of the uterus are closed by the contraction of its walls, and hæmorrhage is avoided. The mother must eliminate during pregnancy not only the waste of her own organism, but also that of the fœtus. Hence the kidneys, being overworked, are occasionally the cause of uræmic convulsions.

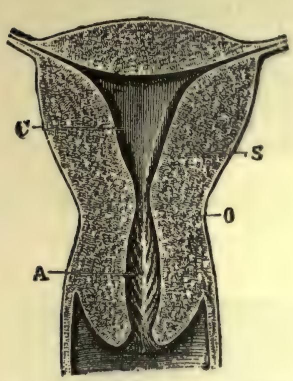

Fig. 392.—Virginal Uterus. (Grandin and Jarman.)

Action of Agents Upon Uterus.—Fardon has shown that adrenalin increases the contractions of a pregnant uterus. Shaefer has shown that the pituitary extract augments the contractions of the uterus.

Ott and Scott have shown that the ovary, spermine, iodothyrin, pancreas, mammary gland and dried brain produced strong uterine contractions. This action of the ovary has been confirmed by Bell and Hick. Calcium salts and the secretion from the internal surface of the uterus stimulate contraction of the uterus, according to Bell and Hick.

Enlargement of Mammary Glands in Pregnancy.—Starling found that the injections of a part of the dried embryo of rabbits

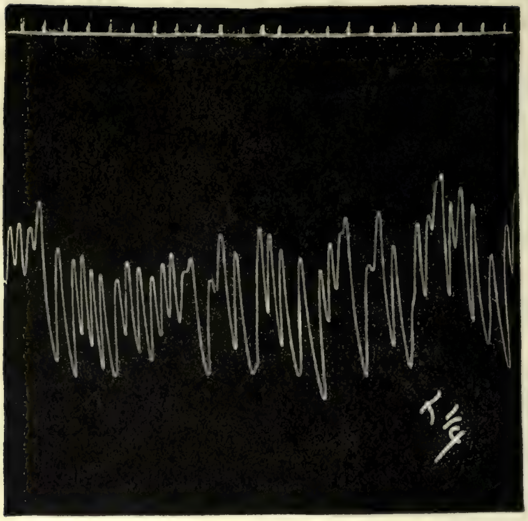

Fig. 293.—Normal Uterine Contraction, Effect of Mammary Gland Extract on Uterine Contraction.

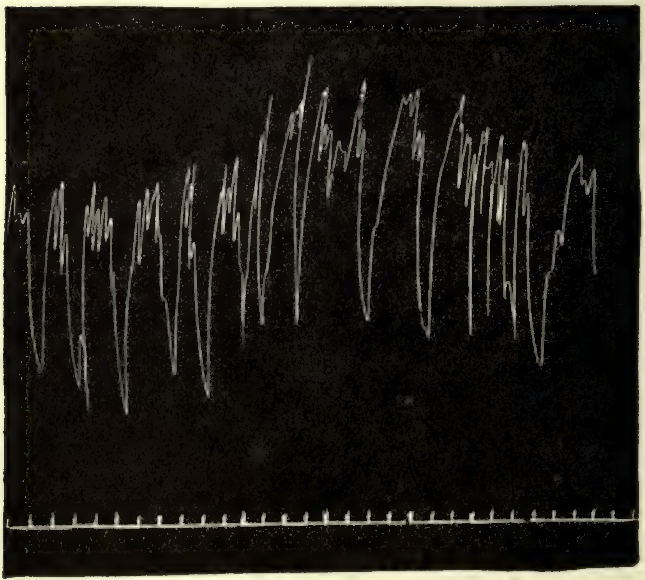

Fig. 393*a*.—After Effect of ¼ Grain of Extract of Mammary Gland. Read from left to right. Time marks every 5 seconds.

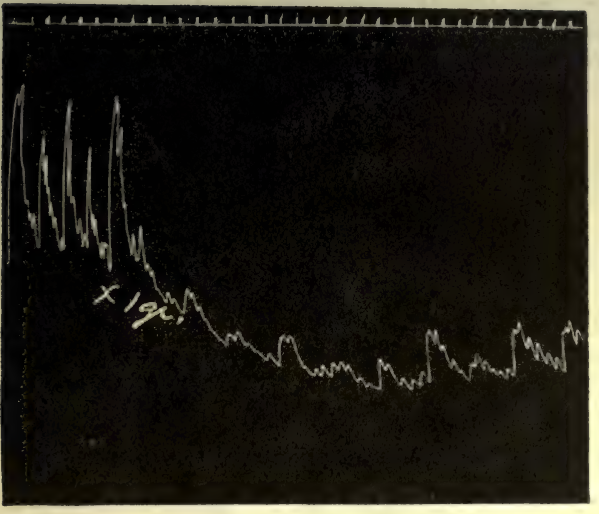

Fig. 393*b*.—Primary Effect of Prostate on Uterine Contractions.

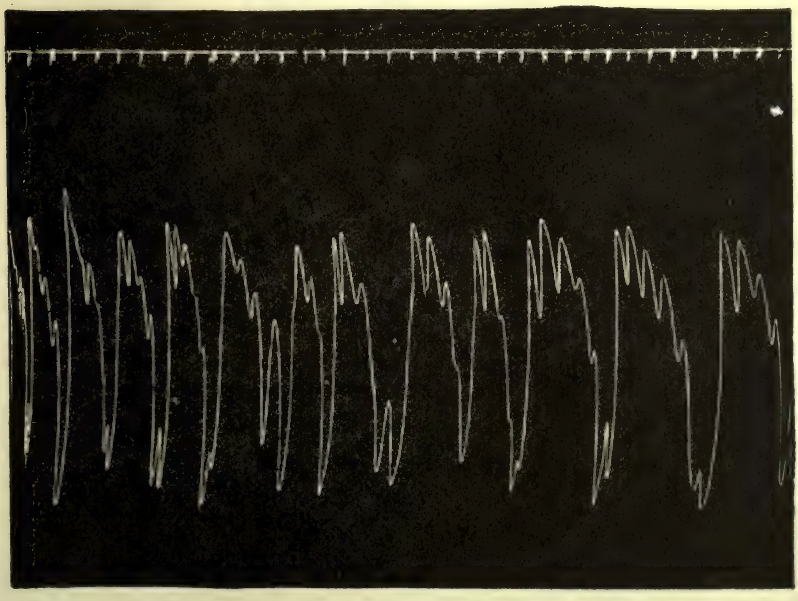

Fig. 393*c*.—After Effect of Prostate on Uterine Contractions.

cause an enormous enlargement of the mammary glands of the rabbit, showing that the sympathetic enlargement of the mammary glands in pregnancy is due to some chemical agent, a hormone, acting through the blood, and not by the nervous system.

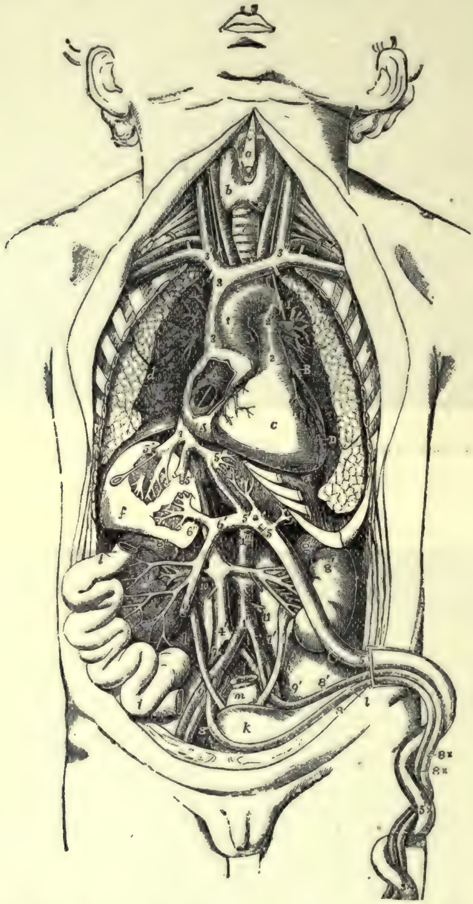

Fig. 393.—The Fœtal Circulation. (Grandin and Jarman.)

Placenta.—The placenta is the *nutritive, excretory,* and *respiratory* organ of the fœtus from the third month to the end of pregnancy. It is discoid in shape, one side being attached to the uterine wall, the other becoming attenuated, to end in the umbilical cord, which is the medium of exchange between the placenta and the fœtus. The villi of the chorion frondosum dip down into the mucous membrane of the uterus, to push against the walls of the large vessels found there and whose structure is similar to that of capillaries. The cells comprising the villi act as an osmotic membrane through which osmosis occurs. By this means oxygen and nutritive lymph pass from the mother's blood to that of the fœtus. On the other hand, the fœtal blood gives off carbon dioxide and probably urea. There is no intermingling of the two blood-currents, since there is always a layer of epithelium to act as a limiting membrane.

Fœtal Circulation.—The blood is brought to the body of the fœtus by the umbilical vein. Some of this oxygenated blood passes through the liver to the hepatic veins, to be emptied into the inferior vena cava. The remainder of the umbilical blood passes into the inferior vena cava through the ductus venosus.

The blood, mixed with that which is returned from the lower extremities, enters the right auricle. Guided by the Eustachian valve, it passes over into the left auricle through the *foramen ovale.* The blood now courses through the left ventricle, aorta, the hypogastric and umbilical arteries to the placenta.

The blood is returned from the head and the upper extremities to the right auricle by the superior vena cava. This stream of blood passes through the auricle and auriculo-ventricular opening directly into the right ventricle, guided by the tubercle of Lower. The blood next passes into the pulmonary artery. Some of it (enough to nourish the solid lung-substance) passes to the lungs, but the major portion passes into the aorta through the ductus arteriosus. When in the aorta it takes the course of the blood from the left ventricle to finally reach the placenta. The blood to the lungs returns to the left auricle through the pulmonary veins.

After birth the umbilical arteries are obliterated with the exception of their lower portions, which remain as the superior vesical arteries. The umbilical vein becomes obliterated and remains as the round ligament of the liver. The umbilicals become impervious soon after cessation of the placental circulation.

The foramen ovale closes, thereby cutting off communication between the right and left hearts. By the second or third day the ductus arteriosus has also become obliterated, to be present in adult life as the ligamentum arteriosum.

These changes in the circulatory apparatus are dependent upon the establishment of pulmonary respiration at birth. The first inspiration is said to be due to a sensory *reflex* from the colder air striking the sensory skin filaments of the chest and abdomen. After the cord is tied there soon follows an increase of CO_2 in the blood. By its presence the activities of the respiratory center of the medulla are instigated. However, the various centers are but feebly irritable at birth and require somewhat heroic stimulation to bring out their activities. This feebleness accounts for the remarkable vitality of the infant and its intense resistance to asphyxiation.

Development and Growth.

When the anabolic and catabolic processes are balanced in adult life, the body remains the same in weight.

The progressive development of the body in height is made in an uneven manner, depending upon different ages. In the first year the growth is about twenty centimeters, in the second year ten centimeters, third year about seven centimeters, from five to sixteen, about five and one-half centimeters each year. In the twentieth year growth is very slight.

Dr. H. P. Bowditch has shown that growth is most rapid during the earliest periods of life. During the first twelve years boys are from one to two inches taller than girls of the same age. At about twelve and a half years girls begin to grow faster than boys, and during the fourteenth year are about one inch taller than boys of the same age. At fourteen and a half years of age boys again become taller, girls having at this period very nearly completed their growth, while boys continue to grow rapidly till nineteen years of age.

On the contrary, the development in thickness and breadth is slower during the first years than at puberty; toward the fortieth and fiftieth years it attains its maximum.

The tissues of the organs may increase in two ways: by increase in volume of existing elements or by the multiplication of new cells.

Bones present certain physiological properties of great interest, for they grow both in length and thickness. The increase in length is at the end of the bone at the junction of the epiphysis with the diaphysis. The increase in thickness is made by means of the periosteum adding new layers of bone on the surface.

EVOLUTION.*

All modern conceptions of the immense multiformity in the animated world are based upon the observed facts of perpetuating

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*Contributed by Dr. P. Fischelis.

established forms by *heredity* and the arising of new forms by *variation.* The main points of discussion are how, when, and where the physiological phenomena of heredity and variation, leading ultimately to *evolution,* set in. While the discussion of these problems has been going on for centuries past, a great stimulus for approaching them in a more rational way has been given by Darwin with the publication of his views of the "Origin of Species." Having observed the great variety of forms produced by breeders of animals and cultivators of plants, through *artificial selection,* he was led to assume that the natural selection has been the cause of the multiformity of animals and plants in nature. It was particularly plausible to accept this view of a gradual development of a new species, if there was taken into consideration the needed *adaptation* to dominating circumstances; the constantly taking place in nature of the *struggle for existence,* with its consequence of the *survival of the fittest;* and last, but not least, the transmission of the changes acquired through the mentioned factors to succeeding generations by *heredity.* It is evident that Darwin based his views only upon facts available at that time and known from observations of adult forms, but these facts alone could not be considered as sufficient evidence for his views. The theory itself, however, was so fascinating that a great number of enthusiastic investigators were induced to study the development of individual animals, and the facts revealed by embryologists at that period have been astonishing. It has been shown that all metazoa develop from ova, that the ova of all animals undergo a similar process of segmentation, and in every case a blastoderm is formed, first consisting of a single layer, but consecutively changing into one of two, and finally one of three layers of cells. The similarity between these early stages in the development of widely different animals has been found to be so striking that it is impossible to distinguish one animal from another at this stage, and these facts gave rise to the *Gastræa* theory of Haeckel in support of the views of Darwin. Haeckel considers that all forms of blastoderms, consisting of two germinal layers, can be looked upon as modifications of the simple gastrula; and as a gastrula is the foundation for the development of a single individual—*ontogenesis*—so a simply constructed animal similar to it is to be considered as the ancestor of all metazoa. He even constructed a treelike diagram to illustrate how, from an undifferentiated being, *gastræa,* by means of the above mentioned factors pointed out by Darwin, an evolution to different types, varieties, and species—phylogenesis—observed in the animal world, could take place. Haeckel has published his views not only for scientific readers, but, through his popular publication, he, more than any one else, made the discussion of the problems of evolution and inheritance accessible to the public at large; and the literature, scientific as well as unscientific, called forth by his efforts, for and against this theory, is enormous. The scientific investigations, however, have failed to show as yet a single instance of a gastrula, or its modification, developing into any other animal than one similar to that from which it itself originated. On the other hand, it has been conclusively shown that the physiological differentiation of the cells constituting the blastoderm is established long before the germinal layers are distinctly differentiated. We must, therefore, conclude that the lever for lifting the mystery of our phenomena is to be applied at an earlier period than the already formed blastoderm. The facts, which have accumulated within recent years, on the morphology of the cell and its physiological manifestations during the process of reproduction have, as we have seen above, been astonishing. Particularly the nucleus has attracted the most attention, and it has been shown very conclusively that the chromosomes of the nuclei of the sexual cells are the principal factors in transmitting the hereditary manifestations during reproduction. The most recent studies, particularly those of Conklin, have revealed the fact, however, that the cytoplasm of the egg-shell also has a more highly differentiated structure than was suspected. It has been conclusively shown that many of the future organs are already mapped out in the two-cell stage, and even in the unsegmentated ovum.

It was only natural that these new discoveries should exercise great influence upon the conception of evolution, and therefore a new theory, embodying all the newest achievements, could be expected to be received with favor. This new theory is suggested by *De Vries* as the *"mutation theory,"* and is founded upon the phenomena of the cell-life. It is a theory of evolution of living organisms through evolution of their germ-cells, and suggests, in the words of Conklin, that similarities in the character and localization of the material substances of the egg must be the initial causes of all similarities or homologies which appear in the course of development. Modifications of this germinal organization, however produced, are probably the immediate causes of evolution; and if it is to be accepted as probable that certain types of animals have been derived from others, it is evident that such transformations might be accomplished far more easily in the egg than in the adult. Relatively slight modifications in the germinal organization would convert one type into another.

We find here the question raised, whether *sudden* alterations of germinal organization may not lie at the base of the origin of new types.

How much nearer this new theory will bring us to the proper conception of the physiological "phenomenon of life" itself and the "phenomenon of reproduction" of living beings, as a manifestation of the preservation of energy underlying the former, remains to be seen. The solution of the ultimate and most mysterious of all problems—the question of the "origin of life"—seems to be as remote as ever.

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Volume. English to French.

1 cubic inch = 16.3861759 centimeters cubes.
1 fluid ounce = 28.3495 “
1 pint = 567 “
1 cubic foot = 28.3153 liters.

Volume. French to English.

1 centimeter cube = 0.061027 cubic inch.
1 liter (1000 c.c.) = 61.027 cubic inches,
or 35 fluid ounces,
or $1^3/_4$ pints.
1 meter cube (1000 liters) = 35.3 cubic feet.

Measures of Energy.

1 kilogrammeter = about 7.24 foot-pounds.
1 foot-pound = “ 0.1381 KgM.

Mechanical Equivalent of Heat.

1 kilocalorie = 424 (or 423.985) kilogrammeters.

Fahrenheit and Centigrade Scales.

To convert Fahrenheit into Centigrade subtract 32 and multiply by $^5/_9$.

To convert Centigrade into Fahrenheit multiply by $^9/_5$ and add 32.

INDEX.

ABDOMINAL reflex, 679
Abducent nerve, 827
    distribution, 827
    function, 827
    origin, 827
    pathology, 827
    physiology, 827
Aberration, 794
  chromatic, 794
  spherical, 794
Absorption, 135
  by blood-vessels, 163
  by the skin and lungs, 164
  from intestines, 144
    stomach, 144
    within, 135
    without, 135
  of alcohol, 144
    carbohydrates, 145
    fats, 147
    proteids, 146
    salts, 145
    water, 145
  rapidity of, 148
  time of, 149
Accessory foods, 44
Accessory nucleus dentatus, 686
Accommodation of the eye, 795
  act of, 794
  defects of, 794
  for distance, 796
  mechanism of, 795
Acetic acid fermentation, 128
Acetonæmia, 124
Achromatic nuclear substance, 12
Achroodextrin, 63
Acid fermentation of urine, 455
Acid poisoning, 486
Acid sodium urate, 447
Acids in the gastric juice, 75
Acromegaly, 420
Adam's apple, 565
Adaptation, 868
Addison's disease, 414
Adenin, 417
Adipocere, 544
Adrenal glands, 412
    blood supply of, 414
    choline secretion, 413
    extract of, 416
    function of, 414
    results of extirpation of, 414
    secretory nerves of, 417
    structure of, 412
Adrenalin, 416
Aeroplethysmograph, 356
Æsthesiometer, 732
Afferent impulses of cerebellum, 692
After-images, 809
Age, influence on capacity of respiration. 354
Agglutinins, 215
Agraphia, 573
Aim of alimentation, 488
Air, 393
  complemental, 355
  compressed, 394
  quantity breathed, 355
  rarefied, 395
  reserved, 355
Air, residual, 355
  tidal, 355
  vital capacity of, 355
Air cells, 342
Air passages, 338
Air tubes (see bronchi), 338
Ala cinerea, 628
Alanin, 33
Albumin, 35
  alkali, 35
  acid, 35
  derived, 35
  egg, 36
  in urine, 459
  native, 36
  serum, 36
Albuminuria, 459
  causes, 459
  tests, 459
Albuminates, 35
Albuminoids, 35
Albumoses, 85
Albumosuria, 458
Alcohol, 44
  heat value of, 500
Alcoholic fermentation, 128
Aleuron granules, 35
Alexia, 573
Alimentary canal, 47
    length, 47
  parts of, 47
  substances, 38
Alkali albumin, 35
Alteration theory of nerve currents, 595
Alternate hemiplegia, 693
Alveolus, 51
Amido acids, 34, 476
Ammonia, 33, 450
Ammonium carbonate, 445
  magnesium phosphate, 458
Amnion, 856
Amœba, 9, 15
Amœboid movement, 15
Amphipyrenin, 13
Ampulla, 769
Amyloses, 28, 29
Amyloses or starches, 29
  action of saliva upon, 63
    pancreatic juice, 104
Amylopsin, 104
Anabolic processes, 468
Anatomy, 3
Animal heat, 506
    estimation of, 513
    extremes of temperature, 512
    post-mortem rises, 527
Animals, 509
  cold blooded, 509
  temperature of, 509
  warm blooded, 509
Anions, 136
Ankle clonus, 629
Anosmia, 747
Anospinal center, 131
Anterior columns, 617
  root fibers, 617
  pyramids, 625
Antero-lateral ascending cerebellar tract, 619
Antero-lateral ground bundle, 617

Antiferments, 86
Antipepsin, 86
Antiperistalsis, 95
Antiseptic action of hydrochloric acid, 86
Antitoxins, 214
Anus, 94
Aphasia, 572
Aphemia, 573
Aphonia, 572
Apnœa, 373
Aqueductus Sylvius, 639
Aqueous humor, 788
Arachnoid, 609
Arcuate fibers, 632
    superficial, 632
    deep, 632
Areas of Cohnheim, 533
Arginine, 107
Argyll-Robertson pupil, 813
Aromatic amino acids, 33
Arterial blood, 170
Arteries (see names of), 278
  bronchial, 343
  coats of, 279
  contractility of, 287
  coronary, 246
  elasticity of, 285
  lymph-spaces of, 154
  muscularity of, 279
  nerve supply of, 280
  pressure of blood in asphyxia, 374
  pulmonary, 233
  pulse, 287
  rate of movement of blood in, 313
  structure, 278
  tension, 296
  vasa vasorum, 279
Artery of cerebral hæmorrhage, 659
Articulate sounds, classification of, 571
    vowels and consonants, 571
Artificial respiration, 375
    Laborde method, 377
    Marshall Hall method, 375
    Ploman's experiments, 376
    Shäfer method, 376
    Sylvester method, 375
Arytenoid cartilages, 565
Arytenoideus muscle, 567
Ascending loop of Henle, 437
Ase, 61
Aspartic acid, 32
Asphyxia, 373
  artificial respiration in, 375
  causes of death in, 375
  effect upon circulation, 374
  stages of, 373
Aspiration of heart and thorax, 319
Association areas of Flechsig, 703
Aster, 21
Astigmatism, 798
Atmospheric air (see air).
    pressure in relation to respiration, 394
Atoms, 5
Atropine, effects of on heart, 271
    lacrymal gland, 814
    respiration, 364
    salivary glands, 65
Auditory area, 698
  auricle, 750
  cells, 756
    external, 757
    internal, 756
  center, 698
  field, 751
  judgment, 768
  nerve, 757
  sounds, 768
  striæ, 627
Auerbach's plexus, 72
Auricle of the ear, 740
Auricles of heart, 228
  diastole of, 234
  systole of, 234
Auriculo-ventricular valves (see heart valves).
Automaton, 704
Avogadro-Van't Hoff law, 139
Axis cylinder, 601

BACILLUS coli communis, 128
Bacteria, classification of, 127
  digestion by, 128
  fermentation by, 128
  in intestines, 128
Balance of nutritional exchange, 494
Basophiles, 180
Beckman's differential thermometer, 139
Beef tea, 40
Beef toxic principles, 40
Beer, 44
Bell's law, 675
    apparent contradiction, 676
    palsy, 835
Bernard's puncture, 123
Betatetrahydronaphthylamin, 520
Bethe's theory of nerve-cell connections, 600
Bicuspid valve, 225
Bicycle heart, 268
Bidder's ganglion, 253
Bile, 113
  acids of, 114
  action of drugs on, 125
  action on muscles and nerves, 119
  antiseptic powers of, 119
  capillaries, 111
  cholesterin, 117
  composition of, 114
  derivatives of salts and pigments, 115
  ducts, 110
  mucin, 114
  pigments, 115
    in urine, 454
  properties and constituents of, 114
  quantity secreted, 113
  reabsorption of salts, 120
  salts, 114
  specific gravity, 113
  tests for, Gmelin's, 116
    Hay's, 115
    Pettenkofer's, 115
  uses of, 118
Bilirubin, 116
Biliverdin, 116
Binaural audition, 767
Biology, 2
Biuret test, 36
Bladder, 465
Blastoderm, 844
Blind spot, 800
Blood, 166
  arterial, 170
  buffy coat, 204
  carbon dioxide in, 200
  cause of movement of, 231
  circulation of, 229
    schema, 283
  coagulation of, 201
  color of, 166
  composition, 189
  crystals, 190
  distribution of, 170
  difference between arterial and venous, 170
  experiments upon, 177
  fibrin of, 20
  function of, 211
  globucidal action of, 209
  gases of, 200
  hæmoglobin, 188

Blood, laking, 177
  medico-legal tests, 211
  odor, 168
  oxygen in, 200
  pigments in urine, 452
  plasma, 197
  plates of, 183
  proteids of, 198
  quantity of, 169
  reaction, 167
  renewal of, 208
  serum, 197
  specific gravity, 168
  spectra, 194
  taste, 168
  temperature of, 168
    estimation of, 169
  transfusion, 209
  volume of, 198
    Welcker's estimation, 169
  venous, 170
Blood-corpuscles, 171
    blood-platelets, 183
    chemical composition of, 189
    chemistry of, 197
    count of, 174
    destruction of, 186
    diapedesis of, 182
    experiments upon, 177
    of different animals, 209
    parasites, 172
    vitality of, 174
  red corpuscles, action of inorganic substances, 178
    destruction of, 186
    formation of, 185
      in extra-uterine life, 186
      in intra-uterine life, 185
    function of, 211
    life cycle of, 174
    methods of counting, 174
    number, 173
      conditions affecting, 173
    parasites, 172
    place of destruction, 187
    rouleaux, 172
    shape, 171
    size, 171
  white corpuscles, 179
    amœboid movements of, 180
    disappear when blood is drawn, 179
    function of, 181
    number of, 179
    origin of, 183
    structure of, 180
    variations in number, 179
    varieties, 180
    where found, 181
Blood-crystals, 190
Blood-platelets, 183
Blood-pressure, 296
    effect of vagus on, 368
    extremes of, 307
    in man, 303
    measurement of, 299
    pathological, 307
    respiratory wave, 302
      causes, 302
    Traube-Hering curve of, 308
    variations of, 306
    venous, 309
Blood-vessels, 284
    circulation in, 284
      Weber's schema, 283
Body, chemical constituents of, 25
Bowditch stair-case contraction, 273
Body cavity, 6
Bony labyrinth, 753
Bowman's capsule, 436
Boyle-Van't Hoff law, 139
Boveri on fertilization, 849
Brain (see cerebellum, pons, etc.).
  action of extracts of, 706
  aqueduct of Sylvius, 639
  artery of hæmorrhage, 659
  blood-supply of, 658
  circulation in, 319
  claustrum, 653
  corpora quadrigemina, 654
  corpora striata, 658
  external form, 642
  extirpation of, 695
  fissures of, 642
  fourth ventricle, 638
  ganglia of, 650
  gray matter of, 648
  internal capsule, 654
  lobes, 645
  motor areas, 697
  optic thalamus, 695
  sensory areas, 697
  structure of convolutions of, 649
  tracts, cortico-pontal cerebellar, 656
    motor, 656
    sensory, 658
  white matter, 650
Bread, 43
Bread juice, comparative value of, 79
Breathing (see respiration).
Bromelin, 104
Bronchi, 342
  blood-supply of, 343
  unstriped muscle, 363
Bronchial system, 342
Brunner's glands, 93
Buffy coat, 200
Bulb (see medulla).
Bulbar nerves, 682
Burdach's column, 621
Butter, 43
Buttermilk, 43
Butyric fermentation, 128

CACHEXIA strumipriva, 404
Cæcum, 94
Caffeine, 45
Caissons and effect of compressed air, 394
Caisson paralysis, 394
Calamus scriptorius, 627
Calcium carbonate, 458
  oxalate, 458
  phosphate, 458
Calorie, 500
Calorimeter, 514
Calyces of kidney, 435
Camera obscura, 793
Canal, alimentary, 47
  external auditory, 750
    function, 750
  Petit's, 788
  Schlemm's, 775
  semi-circular of ear, 768
  Stilling's, 788
Cannon's experiments on stomach, 73
Capacity of chest, vital, 354
Capillaries, 280
  anatomy of, 280
  bile, 111
  blood-pressure in, 309
  capacity, 280
  circulation in, 281
  histology, 280
  passage of corpuscles through walls, 294
  rate of blood in, 296
  size, 280
Capillary circulation, 292
  blood-pressure, 309
  swiftness, 296
Capsule of Bowman, 436
  of Glisson, 109

Capsule of Tenon, 789
Carbamid, 443
Carbohydrates, 27, 38
  absorption of, 145
  heat value of, 500
    in metabolism, 479
Carboluria, 454
Carbon equilibrium, 493
    estimation of, 493
Carbon monoxide, 393
Carbon monoxide hæmoglobin, 192
Carbonic acid, 392
    in blood, 200
    in urine, 455
Cardiac glands, 70
  impulse, 236
  mucous membrane, 76
  pathology, 332
  revolution, 234
  sphincter in vomiting, 87
  sympathetic, 711
Cardinal points of Gauss, 792
Cardiograms, 238
Cardiographs, 236
  Sanderson's, 236
Cartilages of larynx, 564
Caseanic acid, 108
Casein (see milk), 42
Caseinogen, 42
Catabolic processes, 468
Cataract, 782
Cathions, 136
Cauda equina, 608
Caudate nucleus, 651
Cell-division, 17
    direct, 19
    endogenous nuclear multiplication, 22
    indirect, 20
Cells, 1, 7
  achromatin, 12
  afferent, 605
  animal and vegetable, differences, 5
  blood (see blood-corpuscles).
  ciliated, 15
  constituents, 7
  definition, 7
  Deiters's, 693
  efferent, 605
  fatigue of, 23
  gustatory, 739
  Langerhans's, 100
  nerve, 596
  Nissl granules, 599
  nuclear sap, 12
  nucleolus, 13
  nucleus, 12
  olfactory, 744
  oxyntic, 71
  parietal, 71
  Purkinje's, 689
  selective power of, 136
  tactile, 728
  theory of, 5
  vegetable, 6
  wall, 8
Cellulifugal fibers, 605
Cellulipetal fibers, 605
Cement, 54
Center of smell, 698
Central nucleus, 636
Centrosome, 13, 21
  definition, 13
  division of, 14
  number, 14
  size, 14
  staining of, 14
Cereals, 44
Cerebellum, 684
  accessory nucleus dentatus, 686
  afferent impulses, 692
Cerebellum, arbor vitæ, 686
  center of coördination, 692
  corpus dentatum, 686
  cortex, structure of, 687
  efferent impulses, 692
  experiments on, 691
  function of, 692
  general description, 685
  internal structure, 687
  nuclei of, 686
  median lobe, 685
  peduncles, 693
  Purkinje cells, 687
  section of, 693
  spinal cord connections, 688
  surface form, 685
  valley of, 685
Cerebral convolutions, structure of, 649
Cerebral cortex, 649
    ablation, 704
    action of brain-extracts on, 706
    motor centers, 697
    sensory centers, 698
Cerebral detrusor center, 466
Cerebral hemispheres, experimental physiology of, 704
    effect of destruction, 704
    irritability of cortex, 706
Cerebral peduncles, 636
    crusta, 637
    locus niger, 637
    tegmentum, 638
    texture, 637
Cerebrins, 607
Cerebrospinal fluid, 709
    action of drugs on, 710
    composition, 709
    differences from plasma, 709
    origin, 709
Cerebrum (see brain).
Cerumen, 750
Chambers of eye, 788
Champagne, 45
Charcot's artery of hæmorrhage, 659
Cheirokinesthetic center, 573
Chemical composition of the body, 25
Chemiotaxis, 16
Chest in respiration, 349
  voice, 565
Cheyne-Stokes respiration, 378
Chlorides in urine, 454
Chlorophyll, 191
Chlolagogues, 125
Chloroform on electrical responses, 594
Cholesterin, 116
Cholin, 413
Chorda tendineæ (see heart).
Chorda tympani, 64
Chorion, 856
Chorium frondosum, 856
Choroid coat of eye, 776
Chromatic aberration, 794
Chromatic nuclear substance, 12
Chromatolysis, 599
Chromogen, 413
Chromosomes, 21
Chyle, 159
  coagulation of, 159
  composition, 159
  corpuscles, 159
  flow, 159
  quantity, 163
Chyme, 87
Cilia, 15
Ciliary movement, 15
  body, 779
  ganglion, 831
  muscles, 778
  processes, 778
  system, 789

Cilio-spinal center, 681
Circles of diffusion, 801
Circulation, 229
  action of heart, 231
  capillary, 292
  comparative, 219
  course of, 229
  duration, 317
  early discoveries, 281
  in blood-vessels, 278
    brain, 319
    frog's foot, 294
    lower animals, 219
    portal system, 110, 229
    pulmonary system, 229
    renal system, 439
    systemic system, 229
    venous system, 318
  influence of asphyxia, 374
  pathological conditions of, 342
  of blood, 231
  rapidity, 312
Circulatory system, 229
Circumvallate papillæ, 738
Clarke's column, 615
Claudius's cells, 757
Claustrum, 653
Clava, 627
Climacteric, 859
Coagulation of blood, 201
  conditions affecting, 205
  factors of, 203
  of milk, 42
  process of, tabulated, 203
  rapidity, 201
  theories of, 202
  why it does not in vessels, 207
Coagulases, 62
Cocoa, 45
Cochlea, 754
Cochlear nerve, 757
Coffee, 45
Coffeon, 45
Cohesion of nerves, 607
Cohnheim's areas, 533
Cold-blooded animals, 509
Cold spots, 733
Colloids, 142
Colon, 94
Colon bacillus, 128
Color-vision, 805
  blindness, 807
  phenomena of perception, 806
  sensations, 806
Colostrum, 41
  corpuscles, 43
Comma-tract, 621
Commissures of cord. 622
Complemental air, 355
Complementary colors, 807
Compounds, 25
  inorganic, 25, 26
  organic, 25, 26
Compressed air of caisson, 394
Cones, 734
Conjugate deviation, 756
Conjugated sulphates, 454
Conjunctiva, 773
Conklin's discoveries, 868
Connective-tissue spaces, 154
Contractility of muscle, 539
Contraction of pupil, 781
Convolutions of brain, 645
Cord, spinal (see spinal cord).
Corium, 727
Cornea, 773
Coronary arteries, 246
Corona radiata, 654
Corpora quadragemina, 654
Corpora striata, 650
Corpus callosum, 642
Corpus dentatum, 686
Corpus luteum, 860
  of menstruation, 860
  of pregnancy, 860
  spongiosum, 857
Corpus striatum, 650
Corpuscles (see names of).
Corti arches, 756
  canal, 756
  membrane, 757
  organ of, 756
Cortical epilepsy, 700
Cortico-pontal-cerebellar tract, 637
Coughing, 378
Cranial ganglia, 650
Cranial nerves, 820
    decussations, 820
    origin, 822
    spinal nerves, comparison with, 821
Creatinin, 450
Cremasteric reflex, 680
Cresol, 124
Cretinism, 404
Crico-arytenoid muscle, 567
Cricoid cartilage, 564
Crista acousticæ, 627
Crossed pyramidal tract, 619
Crowbar case, 705
Cruciate centers, 521
Crusta, 637
Crusta petrosa, 54
Cryoscopy, 139
Crystalline lens, 781
Crystalloids, 142
Cuneate nucleus, 628
Cuneus, 699
Cupola, 754
Curdling ferments, 77
Currents, nerve, 593
Cutis vera, 727
Cytotoxins, 216
Cystic duct, 112
Cystine, 458

DALTONISM, 807
Darwin on evolution, 867
Descemet's membrane, 774
Decidua reflexa, 853
Decidua serotina, 853
Defecation, 131
  center, 132
  mechanism of, 132
Degeneration of nerves, 676
Deglutition, 58
  of fluids, 59
  of solids, 58
  (see swallowing.)
Dehydration, 468
Deiter's process, 600
  nucleus, 691
Daland's hæmatocrit, 176
Demarcation current, 591
Demodex folliculorum, 734
Dendrons, 600
Depressor nerve, 266
Dermis, 725
Descending tubule of Henle, 437
Development and growth, 866
Devries's mutation theory, 868
Dextrins, 29
  achroodextrin, 29
  erythrodextrin, 29
Dextrose in urine, 460
Diabetes, 552, 122
  adrenalin, 122 413
  experimental, 122
  inhalation, 123
  irritation of vagus and depressor, 124
  pancreatic, 107

Diabetes, phloridzin, 119
  section of cord, 123
Diabetic puncture, 123
D'Jelitzin's artificial respiration, 377
Diamino acids, 32, 475
Diapedesis, 182
Diaphragm in respiration, 348
Diaster, 22
Diastase, 29
Diastole of heart, 234
Dibasic acids, 107
Dicrotic wave, 291
Diet, 498
  Chittenden's experiments, 502
  energy table, Hall, 502
    Atwater, 493
Diffusion, 137
  digestion, 46
  changes in the mouth, 64
  divisions of, 48
  gastric, 79
  intestinal, 125
  in large intestines, 128
  mechanism of, 128
Dioptrics, 793
Diphtheria toxin (immunity), 213
Diplopia, 805
Direct cell-division, 19
Direct cerebellar tract, 619
Direct pyramidal tract, 617
Discus proligerus, 847
Double vision, 810
Doyere's eminence, 536
Dropsy, 144
Drug pigments in urine, 454
Dubois-Reymond coil, 582
Ductless glands (see names of).
Ductus arteriosus, 865
Ductus cochlearis, 755
Ductus communis choledochus, 112
Duodenum, 89
Duplication, 468
Dura mater, 609
Dynamometer, 558

Ear, 749
  anatomy, 749
  bones, 752
  description, 752
  external, 750
    function, 750
  internal, 753
    function, 766
  middle, 751
    transmission by air of, 761
    transmission in, 761
Ectoderm, 5, 11
Eck's fistula, 445
Efferent fibers of sympathetic, 714
Eggs, 39
Ehrlich's theory of immunity, 214
Ejaculation, 857
Elastin, 38
Elasticity, 556
Electrodes, non-polarizable, 579
Electrolytes, 135
Electrometer, 589
Electromotivity, 587
Electrophysiology, 575
  Dubois-Reymond coil, 583
  electrical phenomena of contracting muscle, 589
  negative variation of nerve-currents, 593
  nerve-muscle preparation, 587
  physiological rheoscope, 588
Electrotonic variations, 670
Electrotonus, 666
  Loeb's theory of, 668
  phenomena, 1
Elements, 5
  in body, 25
Embryology, 845
Emetics, 88
Emmentia teres, 639
Emmetropic eye, 796
Emulsification, 30
Enamel, 54
End-bulbs, 729
Endocardiac pressure, 239
Endocardium, 225
Endogenous nuclear multiplication, 22
Endolymph, 765
Endomysium, 529
Endoneurium, 604
Energy, 506
  kinetic, 434
  potential, 507
Enterokinase, 126
Entoderm, 844
Enuresis, 680
Enzymes, 62
  classification of, 62
  hydrolytic action of, 62
Eosinophiles, 180
Epiblast, 855
Epidermis, 725
Epigastric reflex, 679
Epiglottis, 565
Epineurium, 603
Epimysium, 529
Erection, 857
Ergograph, 559
Erepsin, 125
Erythroblasts, 172
Erythrodextrin, 29
Esophoria, 811
Ether on electrical responses, 594
Eustachian tube, 762
Evolution, 867
Exercise, effect on temperature, 511
Exophoria, 811
Expiration, 350
  center, 364
  complex, 350
  effect on blood-movement, 360
  movements of, 344
  muscles of, 345
  simple, 345
External auditory meatus, 749
  capsule, 653
Eye, 772
  accommodation for distance, 796
  after-images, 809
  blood-vessels, 775
  coats, 772
  coördinated movements, 809
  general description, 772
  imperfections and corrections, 797
  lymphatics, 790
  measurements, 791
  movements, 812
  muscles, 812
  nerves, 780
  phosphenes, 785
  structure, 772

Facial nerve, 834
    Bell's palsy, 835
    chorda tympani, 834
    distribution, 835
    function, 835
    origin, 834
    pathology, 835
    physiology, 835
Fæces, 129
  amount, 129
  color, 130
  composition, 129
  variations, 129

Falsetto voice, 571
Fasciculi, 529
Fasting, 495
Fatigue of cells, 23
Fats, 29, 43
  absorption, 147
  composition, 29, 30
  heat value, 500
  human fat, 30
  in metabolism, 481
  olein, 30
  origin, 30, 481
  palmatin, 29, 30
  stearin, 30
Fauces, 50
Fechner's law, 725
Fehling's test, 460
Female pronucleus, 849
Fenestra ovale, 752
  rotundrum, 752
Ferments (see blood, milk, digestive juices), 61
  definition of, 62
Fermentation, 128
  acetic, 128
  alcoholic, 128
  butyric, 128
  lactic, 42, 128
  oxalic, 128
  tests for sugar, 460
Fertilization, 849
Fever, 524
  metabolism in, 504
Fibers, muscular, 530
  length of, 530
Fibrin, 199
Fibrin ferment, 199, 202
Fibrinogen, 37, 198, 202
Fifth cranial nerve (see trigeminus).
Filiform papillæ, 737
Fillets, 640
Filtration secretion, 398
  theory of lymph, 161
Filum terminale, 608
Fistula, gastric, 81
Flechsig's association areas, 701, 703
    frontal, 703
    parieto-occipito frontal, 703
    insular, 703
Flour, wheat as a food, 44
Fœtal circulation, 865
Foods, 43, 44
  accessory, 44
  caloric value, 500
  chemical constituents, 24
  daily amount, 39
  definition, 24, 488
  vegetable, 43
Formatio reticularis, 629
Fourth cranial nerve (see trochlear).
Fourth ventricle, 633, 633
  boundaries, 633
  floor, 633
Fovea centralis, 786
Fovea hemielliptica, 754
Fovea hemispherica, 754
Fovea posterior, 639
Freezing point, 139
Function, 4
Fungiform papillæ, 737
Funiculus cuneatus, 628
  gracilis, 628
  teres, 639

GALL-BLADDER, 112
Galvanometer, 588
Ganglia of heart, 251
Gases of intestines, 129
Gastræa theory of Haeckel, 868
Gastric digestion, 82
Gastric juice, 74
    action of, 82, 84
    action of bacteria, 86
    chemical analysis, 75
    composition of, 75
    excitants of flow, 74, 80
    effects of bitters, 82
    fat-splitting ferment, 84
    fistula for, 75
    flow of, 78
    function, 84
    methods of securing, 81
    mixed, 84
    pepsin of, 83
    reaction of, 75
    secretion of, 75
    specific gravity, 75
    theory of non-digestion of stomach, 86
    varies in composition and rate of secretion, 78, 79
Gastrula, 851
Gay-Lussac-Van't Hoff law, 139
Gelatin, 38
Geniculate bodies, 650
Genito-spinal center, 680
  urinary apparatus, 465
Germinal cells, 841
    epithelium, 843
Germplasm, 841
Genu, 654
Giantism, 420
Glands (see names of).
Glands of intestines, 93
Glass-blower's pulse, 392
Glisson's capsule, 110
Globulins, 36, 37
Glomerules of kidney, 437
Glossokinesthetic center, 573
Glossopharyngeal nerve, 68, 835
    distribution, 834
    function, 834
    origin, 834
    pathology, 834
    physiology, 834
Glottis, 568
Glucose, 28
  secretion, 123, 684
Glycocholic acid, 115
Glycogen, 120, 121, 122
Glycosamin, 108
Glycosuria, 122
Gmelin's test for bile, 116
Golgi stain, 601
Goll's column, 631
Gower's column, 619
Graafian follicle, 860
Gram calorie, 513
Gram molecule solution, 140
Grandry corpuscles, 729
Gray matter (see cerebellum, etc.).
Great longitudinal fissure, 642
Great transverse fissure, 642
Growth and development, 866
Guaiac test for blood, 211
Gullet (see œsophagus).
Günsberg's test for hydrochloric acid, 87
Gustometer, Sternberg's, 740
Gyrus, fornicatus, 647
    hippocampus, 648

HABENULA, 650
Hæmacytometers, 174
  Thoma-Zeiss, 175
Hæmaglobinuria, 453
Hæmianopsia, 819
Hæmatachometer, 314
Hæmatoblasts, 183
Hæmatocrit, 177
  Daland's, 177
Hæmatoidin, 191

Hæmatoporphyrin, 191
Hæmatin, 190
Hæmin, 191
  chemical properties of, 191
  crystals, 190
  tests for, 191
Hæmochromogen, 194
  spectrum, 194
Hæmoglobin, 188
  amount, 194
  characteristics, 188
  composition, 188
  crystallization, 187
  estimation of percentage, 195
  reduced, 190
  variations in amount, 190, 194
Hæmolysins, 178
  physiological analogy, 178
Hæmometer, 195
  Dare's, 197
  Von Fleischl's, 195
Hæmorrhage, 208
  effects of, 208
  quantity of blood in, 208
Hair, 754
  chemical composition, 735
  function, 735
  general description, 735
Hale's blood-pressure experiments, 299
Hay's test for bile, 115
Hearing, 749
  anatomy of organ of, 749
  auditory nerve, 757
  binaural audition, 767
  Eustachian tube, 762
  general description, 749, 750
  organ of Corti, 756
  semi-circular canals, 768
  sense of, 725
  theory of, 766
Heart, 221
  accelerator center, 269
  action of vagus on, 261
  areas of audibility, 245
  arteries, 247
  auricles, 228
  causes of sounds, 244
  changes in shape and position, 233
  chordæ tendineæ, 225
  course of blood in, 229
  diphasic variation of, 593
  effects of drugs on, 271
  endocardium, 225
  foramen ovale, 222
  foramina Thebesii, 222
  frequency, 248
  ganglia of, 251
  His's muscular bundle, 255
  histology of, 226
  innervation of, 251
  lymphatics of, 222
  minimal stimuli, 272
  moderator center, 261
  movements of, 231
    to clinicians, 231
    persistence of, 241
  muscles of, 221
  musculi pectinati, 222
  myocardium, 224
  nerves of, 260
  nutrition of, 247
  papillary muscle, 224
  position of valves, 245
  refractory period of, 273
  revolution of, 234
  rhythm of, 252
  sinus of Valsalva, 225
  size and shape of, 221
  sounds of, 242, 243, 244
  stair-case contraction, 273
Heart, Stannius's experiments, 272
  stimuli, 272
  structure of, 225
  sympathetic fibers to 269
  valves of, 225
    mitral, 225
    position, 245
    semilunar, 225
    tricuspid, 224
  ventricles of, 229
  work of, 249
Heat (see temperature).
  animal, 506
  estimation of, 513
  latent, 507
  other sources, 508
  radiant, 507
  theory of, 507
Heat-spots, 733
Heat value of food, 500
Heat unit, 513
  calorie, 513
  calorimeter, 514
Height, relation to lung capacity, 354
Helicotrema, 755
Heller's nitric acid test, 459
Hematoporphyrin, 191
Hemianopsia, 818
Heidenhain's lymphagogues, 162
  theory of secretion, 162
Hensen's cells, 757
Hensen's disk, 532
Heredity, 867
Hering's theory of color, 807
Hiatus, 755
Hibernation, 510
Hiccough, 378
Hippuric acid, 449
    formation of, 449
    where secreted, 449
His's muscular bundle of heart, 255
Histology, 3
Histones, 38
Hoarseness, 572
Hormone, 80, 101
Horopter, 803
Hunger, 132
Hyaloplasm, 9, 596
Hydræmia, 211
Hydrochloric acid, 75
    ion theory of, 77
    stimuli for secretion, 77
    test for (Günsberg), 87
Hydroxamino acids, 108
Hypermetropia, 796
Hyperosmia, 747
Hyperphoria, 811
Hyperpyrexia, cause of death, 527
Hypoblast, 855
Hypoglossal nerve, 840
    anastomoses, 840
    origin, 840
    pathology, 840
    physiology, 840
Hypoxanthin in urine, 450

IGNOTIN, 40
Ileocæcal valve, 93
Ilium, 89
Image, formation on retina, 803
Immunity, 213
Inanition or starvation, 495
Incus, 753
Indican, 453
  test for, 453
Indigestible residue of fæces, 130
Indirect cell-division, 20
Indol, 128, 130, 453
Inferior vermiform process, 685
Infundibulum, 342

Inheritance, 867
Inoculation (see immunity).
Inorganic salts of fæces, 130
Inosite, 543
Insalivation, 58, 63
Inspiration, 346
  expansion of chest in, 348
  extraordinary, 349
  movements of, 348
  movements of blood in, 358
  muscles of, 348
Inspiratory center, 365, 682
Intensity of sound, 563
Intermedio-lateral column, 615
Intermittent afflux apparatus, 286
Internal capsule, 654
Interpeduncular space, 637
Interstitial slits, 154
Intestinal digestion, 126
Intestine, 89, 93
  blood-supply, 92, 93
  coats, 90, 94
  digestion in, 126
  gases, 129
  glands, 93
  large, 93, 94
  length, 89
  movements of, 94
  nerve-supply of, 95
  small, 89
  structure, 90
Intracellular ferments, 28
Intraocular pressure, 790
Intrapleural pressure, 359
Intrathoracic pressure, 358
Inunction, 164
Inverted images, 803
Invertin, 28
Iodothyrin, 406
Ions, 135
  necessary for solution, 136
  system of naming, 136
Iris, 779
  ciliary processes, 777
  nerves, 780
  pigment, 780
  reflex, 684, 780
  reflex movement of, 780
  uses, 780
Iron, 27
Irradiation, 808
Irritability of muscle, 539
  of nerve, 732
Ischuria, 442
Islets of Langerhans, 99, 106
Isotonic solution, 140, 178, 275

Jacobson's nerve, 836
Jaundice, 125
Jecorin, 117
Jejunum, 89
Juices (see names of).

Karyokinesis, 20
  stages of, 22
  time of, 22
Keratin, 38
Kephir, 42
Kjeldahl process, 443
Kidney, 431
  blood-vessels of, 439
  calyces of, 35
  capillaries of, 440
  capsule of, 433
  cavity of, 434
  cortex of, 436
  extirpation of, 462
  general description of, 433
  glomerules, 437, 439
Kidney, hilus, 432
  lymphatics, 430
  Malpighian corpuscles of, 439
    pyramids of Ferrein, 439
  medulla of, 436
  minute anatomy of, 436
  parenchyma of, 436
  position of, 431
  sinus of, 433
  structure of, 433
  urinary tubules of, 437
Knee-jerk or patellar reflex, 679
Krause's end-bulbs, 729
  membrane, 534
Kumyss, 42
Kymograph, 300
Kyrines, 37

Labyrinth of ear, 753
Lacrymal gland, 812
Lacrymal secretion, 814
Lactalbumin, 42
Lacteals, 92, 148, 149
Lactic acid, 42, 449
    Uffelman's test, 87
Lactic acid bacillus, 42
Lactic fermentation, 42, 128
Lactose, 28, 42
Lamper eel, 2
Lamina denticulatum, 610
  spiralis, 734
Langerhans's cells, 99, 106
Lantanin, 12
Lanterman's incisures, 603
Large intestine, 47, 93, 94
Laryngoscope, 568
Larynx, 564
  anatomy of, 564
  cartilages of, 565
  cavity of, 568
  condition of, 568
  muscles of, 566
  nerves of, 568
  pathology of, 572
  vocal cords of, 568
Lateral chain theory of Ehrlich, 214
Lateral columns, 618
Lateritious deposits, 448
Laughing, 378
Law of Fechner, 725
Laws of sensation, 724
Lecithin, 117
Lemniscus, 640
Lens, crystalline, 781
Lenses, 798
Lenticular nucleus, 651
Leucine, 103, 107
Leucocytes, 179
  eosinophiles, 180
  mononuclear, 180
  polymorphonuclear, 180
  transitional, 180
Leukocytosis, 180
Levulose, 28
Lieberkühn's glands, 93
Life period, 1
Ligamentum denticulatum, 610
Light, 771
  perception of, 792
  theory of, 771
  transmission of, 771
Lime salts in metabolism, 487
Linin, 12
Lipase, 62
  reversible action of, 62, 105
Liquor sanguinis, 166
Lissauer's tract, 621
Liver, 109
  antitoxic function of, 120
  blood-supply of, 110

Liver, daily secretion, 113
  diastase of, 122
  extirpation of, 120
  function of, 112
  gall-bladder, 112
  internal secretion of, 120
  reaction of, 113
  specific gravity of, 113
  structure of, 111
Locus cœruleus, 639
Locus niger, 637, 694
Ludwig's theory of lymph, 161
  strohmur, 313
Lungs, 340
  air-pressure in, 359
  air sacs, 342
  blood-supply, 343
  color, 341
  coverings, 344
  diffusion of gases within, 382
  lobes, 340
  lymphatics, 344
  medico-legal test, 341
  nerves, 344
  roots, 340
  structure, 342
  vital capacity, 355
Luxus consumption, 474
Lymph, 157
  coagulation, 157
  composition, 158
  flow of, 159
  formation of, 161
  quantity of, 163
  relation to nervous system, 160
  theories of secretion, 161
Lymphagogues, 162
Lymphatic glands, 156
Lymphatic system, 154
Lymphatic trunk, etc., 152
Lymphatic vessels, 151, 156
    capillaries, 153
    coats of, 153
    development of, 154
    distribution of, 152
    origin of, 154
    structure of, 152
    valves of, 153
Lymphocytes, 171, 180
  large non-nuclear, 180
  small non-nuclear, 180

MACULÆ, 785
Macula lutea, 785
Magnesium salts in metabolism, 487
Malpighian corpuscles, 3
    of kidney, 439
    of spleen, 410
Malleus, 753
Maltase, 62
Maltose, 28, 29
Maly's theory of gastric secretion, 77
Male pronucleus, 849
Mammary glands, 420
    arteries of, 422
    during pregnancy, 861
    general description, 421
    lymphatics, 422
    nerves, 422
    results of dried, 422, 861
    structure of, 421
Manometer, 299
Marey's intermittent afflux apparatus, 286
  tympanum, 352
Mastication, 57
Mast cells, 180
Mastoid cells, 752
Matter, 1
  living, 1
Maturation of ovum, 847
Matzoon, 42
Meat, 39
Meconium, 130
Medico-legal tests for blood, 211
Medulla oblongata, 623
    ala cincerea, 628
    anterior pyramids, 625
    arcuate fibers, 632
    auditory striæ, 627
    bulbar nerves, 682
    calamus scriptorius, 622
    centers of, 682
    clava, 627
    double conduction, 681
    external form, 624
    fillets, 640
    formatio reticularis, 629
    fourth ventricle, 638
    funiculus cuneatus, 628
      gracilis, 628
    general description, 624
    internal structure, 629
    lateral columns, 631
    nucleus lateralis, 629
    olives, 625
    parts added, 632
    posterior columns, 631
    raphé of Stilling, 629
    restiform body, 625, 627
    trigonum hypoglossi, 628
    weight, 624
    white columns, 630
    white substance, 630
Meissner's plexus, 95
Melanin, 727, 805
Membrana basilaris, 755, 766
  granulosa, 847
  tympani, 760
Membranes of cord and brain, 609
Membranes, mucous (see names of).
Membranous labyrinth, 755
Memory center, 703
Menopause, 859
Mesoblast, 855
Mesoderm, 855
Mesoporphyrin, 191
Metabolism, 467, 474
  anabolic processes, 467
  balance of, 489
  catabolic, 467
  effect of starvation on, 495
  effect of work on, 472
  equilibrium, 490
  general explanation, 467
  of carbohydrates, 479
    fats, 481
    proteids, 477
    salts, 485
  tabulated exchange, 493
Meta-proteins, 35
Metazoa, 844
Methæmoglobin, 192
Mett proteid method, 77
Metric system, 870, 871
Micro-organisms of fæces, 130
Microscopic test for blood, 211
Microspectroscope, 193
  Sorby Browning's, 193
Micturition, 466
Midcerebellar peduncles, 634, 693
Middle ear, 751
Milk, 41
  clotting of, 42
  colostrum of, 43, 424
  cow's, 41
  fats of, 43
  fermentation of, 42
  functional variations of, 43, 424
  matzoon, 42
  microscopically, 41

Milk, proteids of, 42
  quantitative, 41
  quantity secreted, 43
  reaction, 41
  salts of, 43
  secretion of, 43, 423
  specific gravity, 41
  theory of Ottolenghi, 424
  woman's, 43
Milk-curdling ferments, 42
  globules, 41
  sugar, 42
  teeth, 50
Mitosis, 20
  stages of, 22
Modiolus, 754
Mol. solution, 142
Molars, 51
Molecular theory of nerve currents, 594
Molecules, 5
Monamino acids, 32, 107
Mononuclear leucocytes, 180
Monosaccharides, 28
Morphology, 2
Morula, 849
Motion, 1
Motor area, extirpation of, 700
Motor areas, 697
  impulses transmitted, 662
  speech-center, 573
  tract, 655
  writing center, 573
Motor oculi nerve, 823
    distribution, 823
    diplopia, 825
  drugs, action upon, 825
    function of, 823
    origin of, 823
    pathology of, 825
Motor spray, 537
Mouth, 47, 48
Movement in a circle, 693
  of protoplasm, 15
Mucin, 36
Mucous membranes (see names of).
Müller's law, 722
Murexid test, 449
Muscarine, 271
  action on heart, 271
    on respiration, 364
Muscle-curve, 547
    effect of stimuli upon, 549
    summations of stimuli, 552, 553
    tetanus, 554
Muscles, 528
  appearances under polarized light, 535
  as perfect machines, 558
  blood-vessels of, 536
  carbohydrates of, 542
  cardiac, 538
  changes in contraction, 550
  chemical excitants, 47
  chemistry of, 542
  Cohnheim's areas, 533
  contraction period, 547
  constituents of, 542
  contractility of, 539
  curve, 547
  elasticity of, 556
  electrical phenomena of, 590
  extractives, 543
  fatigue, 549
  ferments, 543
  fibers, 534
  general description, 529
  Hensen's disc, 532
  influence of blood upon, 539
  involuntary, 538
  latent period, 547
  longitudinal striations, 532
Muscles, nerve-supply, 536
  nerve-stimuli, 541
    chemical, 541
    electrical, 541
    mechanical, 541
    thermal, 541
  nuclei of, 538
  proteids of, 542
  rate of contraction of, 550
  reaction of, 542
  relation to tendons, 536
  relaxation period, 548
  resting and acting, 550
  rigor mortis, 544
  sarcous elements of, 532
  serum, 543
  sounds of, 555
  striated, 528
  structure, 530
  tension of, 556
  tetanus of, 554
  theories of currents, 591
  tonus, 555
  unstriped, 538
  urea in, 542
  varieties of, 528
  voluntary, 528
  voluntary contractions of, 555
  wave, 550
  wing muscles of insects, 533
  work of, 557
Muscular labor and urea excretion, 546
Muscular sense, 723
    center of, 702
Mutation theory, 869
Myelin, 602
Myogram, 547
Myograph, pendulum, 545
Myopia, 796
Myohæmatin, 542
Myosin, 542
Myosinogen, 542
Myxœdema, 404

NAILS, 735
  function, 736
  general description, 735
Narcotics, 709
Near point of eye, 796
Neosin, 40
Neovitalists, school of, 161
Nerve, comparison with muscle, 659
  effects of anæmia upon, 674
    electricity upon, 666
    temperature upon, 660
  electrotonus, 666
  electrical potential of, 593
    current theories of, 594
  excitability of, 659
  excitability and conductivity, 663
  excitants, 663
    chemical, 663
    electrical, 668
    mechanical, 663
  influence of blood upon, 674
  irritability of, 660
  Kühne's experiment, 662
  Pflueger's contraction laws, 666
  regeneration, 604
  roots of, 622
  stable equilibrium of, 660
  table of degenerations, 622
    ascending, 622
    descending, 622
Nerve-cell, 596
    classification of, 605
    dendrons of, 600
    dimensions of, 601
    fibrils, 600
    neurite, 600

Nerve-cell, Nissl's granules, 599
    nucleolus of, 599
    nucleus of, 599
    prolongations of, 600
    staining, 601
    structure, 596
Nerve-centers, 607
    common points of, 608
Nerve-fibers, 603
    centrifugal, 677
    centripetal, 677
    chemical properties of, 606
    fatigue of, 560, 661
    mechanical properties of, 607
    medullated, 603
    myelin, 602
    neurilemma, 603
    nodes of Ranvier, 603
    non-medullated, 603
    reaction of, 607
    terminations of, 604
Nerve metabolism, 607
Nerve-muscle preparation, 587
Nerve-tissue, 606
    composition, 606
    gray, 605
    reaction of, 607
    structure of, 607
    trunks, 603
    white, 606
Nerve-wave, transmission of, 661
    swiftness of, 663
Nerves of deglutition, 60
  heart, 251, 260
  intestines, 95
  larynx, 568
  Jacobson, 836
  respiration, 364
  salivary glands, 56
  sweat glands, 429
  taste, 738
  tongue, 738
  vasomotor system, 320
Nervous system, 596
    anatomy of, 596
    chemistry of, 606
    extra-cardiac, 251
    lecithin, 606, 607
    metabolism of, 607
    neuroglia, 614
Neurilemma, 603
Neurites, 600
Neuroglia, 614
Neurokeratin, 606
Neutral fats, 29
Neutrophiles, 180
Ninsen's globules, 424
Nissl bodies, 599
Nitrogen eliminated, 493
  equilibrium, 490
  estimation, 493
  in blood, 385
  in respiration, 382
Nodal points of eye, 792
Nodes of Ranvier, 603
Nonsexual reproduction, 842
Nose (see smell).
Novain, 40
Nuclear membrane, 13
  sap, 12
  spindle, 21
  substance, 12
Nuclei of cerebellum, 686
Nuclei pontis, 635
Nuclein, 13
Nucleolus, 12
Nucleoproteids, 36
Nucleus, 7, 11, 13
  composition, 13
  form, 12
Nucleus, number, 12
  relative importance of, 11
  size, 12
  structure, 12
Nucleus, Deiters's, 759, 770
  emboliformis, 686
  fastigii, 686
  globosus, 686
  lateralis, 629
Nutrition, 1
  of heart, 274
Nuttall's guinea-pig fœtus, 128
Nystagmus, 825

OBESITY, 505
  Banting's method, 505
  Oertel's method, 505
Oblitin, 40
Oculomotor, 823
  diplopia, 825
  effect of drugs on, 825
  function of, 823, 824
  pathology of, 825
Odors, 746
Œsophagus, 47, 57
  anatomy, 57
  length, 57
  nerves, 57
Œstrus, 860
Olein, 30
Olfactory bulb, 745
  cells, 745
  mucous membrane, 743
  nerve, 744
  organ, 744
  sensations, 745
Olives, 625, 636
Oncometer, 332, 462
Open pores, 155
Ophthalmoscope, 814
Opsonins, 218
Optic angle (eye), 803
  axis, 802
  commissure of Gudden, 791
  nerve, 786
  thalamus, 650, 695
Organ of Corti, 756
  taste, 737
  voice, 564
Organic compounds in body, 25
Organs, 4
Origin of species, 866
  of life, 869
Orthophoria, 765
Osmosis, 135
Osmotic pressure, 137
    determination of, 138
    of lymph, 140
    proteids, 142
    physiological application, 142
Osseous labyrinth, 754
Ossicles, 753, 763
Otic ganglia, 713
Otitis media, 751
Ovary, 847
  internal secretion, 860
Ovists, 843
Ovum, 847
Oxalic acid, 449
  fermentation, 128
Oxidation, 388
  seat of, 383
Oxybutyric acid, 124
Oxygen in blood, 385
Oxyhæmoglobin, 189
Oxyntic glands, 71

PACINIAN corpuscles, 729
Pain, 731
Palate, 49

Palmatin, 43
Pancreas, 98
  blood-supply of, 99
  composition of, 102
  daily amount, 102
  effects of removal, 105
    injection of extract, 108
  methods of obtaining the juice, 102
  nerve-supply of, 99
  reaction of, 102
  removal of, 105
  secretion of, 99, 100, 101
    adaptation of, 101
    excitants of, 101
  secretory nerves of, 101
  specific gravity, 102
  structure of, 98
Pancreatic juice, 102
    composition of, 102
    ferments, 103
    quantity, 102
    reaction, 102
    specific gravity of, 102
Papain, 104
Papillæ of tongue, 50, 738
Paracerebellar nuclei, 692
Paraglobulin, 37
Paranuclein, 13
Parasympathetic, 712
Parietal cells, 76
Parieto-occipital fissure, 643
Parathyroid gland, 408
Parotid gland, 55
Parthenogenesis, 842
Pathetic nerve, 825
    distribution, 825
    function, 826
    origin, 826
    pathology, 826
Pawlow's stomach, 81
Peduncles of cerebellum, 693
Pelvis of kidney, 434
Pendular movements, 94
Pendulum myograph, 545
Pepsin, 74, 75
Pepsinogen, 76
Peptic digestion, 84
Peptone, 37, 103
Peptonuria, 458
Perception time, 710
Pericardium, 227
Perilymph, 765
Perimeter, 815
Peristalsis, 94
  influence of drugs on, 97
  of intestines, 94
  pendular movement, 95
Perivascular space of His, 154
Permanent teeth (see teeth).
Perspiration, 428
  acidity of, 428
  constituents, 428
  effect of drugs upon, 429
  function of, 430
  insensible, 426
  nerve-centers, 430
  nerves of, 429
  pathological, 430
  relation to lung excretion, 430
  role of, 430
  sensible, 426
  suppression by cold, 430
Petit, canal of, 788
Petrosal nerves, 834
    great, 834
    small, 834
Pettenkofer's test for bile, 115
Peyer's patches, 93
Pfeiffer's phenomenon, 216
Pflüger's contraction laws, 666
Phagocytes, 16, 182
Pharynx, 56
  openings, 56
  anatomy, 56, 57
Phenol, 130
Phenomena of life, 1
Phenylhydrazin test for sugar, 461
Phloridzin, 123
  diabetes, 123
Phosphenes, 809
Phosphoric acid, 454
    sediments, 458
Phrenic nerve, 348
Phylloporphyrin, 191
Phylogenesis, 868
Physical heat, 506
Physiology, 2
Pilomotor nerves, 717
Pia mater, 609
Picrocarmin spectrum, 194
Pitch, 570
Pituitary body, 418
    extirpation of, 420
    extracts of, 419
    lobes of, 418
    position, 418
    size, 418
    structure, 418
Placenta, 864
Plantar reflex, 678
Plasma of blood, 197
    chemical properties of, 197, 198
    gases of, 200, 385
    inorganic constituents of, 198
    method of examining, 198
    organic constituents of, 197
    physical properties of, 197
Plasmodium malariæ, 172
Plasmon, 42
Plethysmograph, 331
Plethora, 210
Pleura, 344
Plexus (see names of).
Pneumogastric nerve (see vagus), 261, 837
    branches of, 837
    function of, 838
    influence on deglutition, 60
      gastric secretion, 81
      heart, 261
      lungs, 366
      pancreatic juice, 101
      vomiting, 88
    pathology of, 838
    physiology of, 838
Pneumograph, 351
Poiseuille's still space, 295
Polar bodies, 847
Polymorphonuclear leucocytes, 180
Polypeptids, 32
    groups, 33
Polysaccharides, 28
Pons Varolii, 632
    center of epileptiform convolutions, 693
    central nucleus, 636
    faces, 632
    general description, 632
    stratum complexium, 634
      profundum, 634
      zonale, 635
    structure, 634
    trapezoid body, 634
Portal circulation, 110
Portal vein, 110
Posterior columns, 620
Posterior fovea, 639
Posterior perforated spaces, 637
Posterior root-fibers, 622
Postganglionic fibers, 711
Precipitin test for blood, 212
Precipitins, 216

Preganglionic fibers, 711
Pregnancy, 861
Prehension, 48
  of cow, 48
    frog, 48
    horse, 48
    man, 48
    squirrel, 48
Presbyopia, 796
Pressure curve of ventricle, 240
Prostate gland, 858
Proœstrus, 860
Protamines, 38
Proteases, 62
Proteid compounds, 36
Proteids, 32, 33
  absorption of, 146
  chemical composition of, 31
  chromoproteids, 36
  classification of, 35
  heat value of, 500
  metabolism of, 477
  nucleoproteids, 36
  of muscle, 542
  where found, 35
Proteins, 35
Proteoses, 37, 134
Prothrombin, 202
Protoplasm, 8
  chemical composition, 9, 10
  constituents of, 10
  definition of, 8
  importance of, 19
  movements of, 14
  movements, rate of, 15
  specific gravity, 10
Protoplasmic movement of leucocytes, 15
Proximate principles, 26
Ptyalin, 61
Pulmonary artery, pressure, 397
  action of drugs upon, 396
Pulse, 87
  dicrotic, 291
  factors necessary for, 288
  glass-blower's, 392
  qualities of, 288
  venous, 310
Pulse, respiration, ratio, 248
Pupil, 780
  cause of dilatation of, 781
Purin, 447
Purkinje cells, 689
Purkinje-Sanson images, 798
Putamen, 652
Putrid products of fæces, 130
Pyloric glands, 71
Pylorus, 69
  closure of, 74
Pyramidal tracts, 617, 618
Pyramids of kidney, 436
Pyrenin, 13
Pyrimidin bases, 33
Pyrrolidine, 32, 108

QUICKENING, 861
Quotient of gases, respiratory, 383

RANVIER, nodes of, 603
Rarefied air, 395
Reaction of time, 710
    of light, 710
    of motor impulses, 710
    of sound, 710
    of touch, 710
Rectum, 132
Reduction division, 849
Referred sensations, 720
Reflex action, seat of, 671
    forms of, 678
    law of coördination, 673
Reflex action, law of irradiation, 673
    laws of, 673
    localization, 673
    other seats, 671
    skin, 681
    swiftness of, 673
    tendon, 679
Reil, island of, 645
Reissner, membrane of, 755
Remak's ganglion, 251
Renal circulation, 440
  oncometer, 462
Rennin, 42, 77, 133
Reproduction, 841
  among higher animals, 842
  among lower animals, 842
  chorion, 856
  epiblast, 855
  fecundation, 849
  fertilization, 849
  fœtal circulation, 865
  hypoblast, 855
  menstruation, 858
  mesoblast, 855
  non-sexual, 842
  ovum, 847
  ovum, maturation of, 847
  parthenogenesis, 842
  placenta, 864
  segmentation, 849
  sexual reproduction, 842
  spermatozoön, 856
    structure of, 856
Reserved air, 355
Residual air, 355
Resonance, 570
Respiration, 334
  abdominal type, 351
  action of drugs upon, 396
  air-passages, 338
  alveoli, 342
  apparatus, 337
  artificial, 375
  bronchi, 341
  carbon monoxide, 393
  center of, 364
  chemistry of, 379
  Cheyne-Stokes respiration, 377
  compressed air in, 394
  curious phenomena of, 364
  effect on blood-pressure, 361
  effect on circulation, 358
  effect on pulse, 361
  expiration, 350
  external, 337
  function of, 336, 337
  function of unstriped muscle of bronchi, 363
  gases in, 385, 393
  inferior costal type, 351
  internal, 337
  inspiration, 346
  lungs, 340
  lymphatics, 344
  mechanism of, 344
  modified movements of, 351, 377
  nasal, 364
  nerves of, 344, 364
  number of, 356
  of different forms of life, 336
  of chick, 336
  of fœtus, 336
  pathological, 364, 397
  pressure in, 357
  quotient of gases, 383
  relation to nervous system, 364
  rarefied air, 395
  sounds of, 352
  superior costal type, 351
  trachea, 338

Respiratory undulations, 308, 368
Restiform body, 627
Rete Malpighii, 727
Reticulated nucleus, 635
Retina, 782
  blind spot, 728
  duration of stimulation, 785
  epithelium, 785
  histological, 783
  hyaloid membrane, 788
  lymphatics, 790
  pigmentary membrane, 785, 787
  rods and cones, 782
  terminal nerve elements, 784
Retinal epithelium, 785
Rheonome of Von Fleischl, 585
Rheotome, differential, 586
Rheoscope, physiological, 588
Rhodopsin or visual purple, 785, 804
Ribs, action in respiration, 346
Rigor mortis, 544
    and tetanus, 554
    cause of, 544
    influence of fatigue, 546
    influence of temperature, 544
Rolando, fissure of, 643
Rosette, 21

SACCHAROSES, 28
Saccule, 770
Saliva, 61
  action on starch, 61
  composition of, 63, 64
  ferment of, 61
  mechanical function of, 58
  reaction of, 63
  reflex centers, 66
  specific gravity of, 63
  temperature variations in, 63
  time of activity, 63
Salivary glands, 55, 56, 64
    action of, 63
      of drugs on, 64
    nerves to, 66
    Pawlow's experiments, 68
    reflex centers of, 68
    structure of, 56
    trophic and secretory fibers, 68
Salts, 27, 92
  in body, 27
  in metabolism, 485
  in urine, 454
Santorini's cartilage, 565
Saponification, 30
Sarcolactic acid, 542
Sarcolemma, 530
Sarcomeres, 532
Sarcoplasm, 532
Sarcostyles, 532
Scala tympani, 755
Scala vestibuli, 755
Scapular reflex, 679
Schäfer's artificial respiration, 375
Schuetz's law, 77
Scheiner's experiments, 802
Schmidt, segments of, 603
Schwann, white substance of, 602
Science, 2
  biological, 2
  physical, 2
Scleroproteins, 37
Sclerotic coat, 772
Sebaceous glands, 733
  function of, 734
Secretin, 101
Secretion, 398
  adrenal, 412
  by filtration, 398
  by glandular desquamation, 399
  external, 420
Secretion, external, mammary, 420
    sweat, 425
    urinary, 431
  internal, 400
  morphological, 399
  pancreas, 99
  pituitary body, 418
  proper, 399
  spleen, 410
  thymus, 417
  thyroid, 400
Sediments in urine, 458
  in acid urine, 458
    alkaline urine, 457
  amorphous, 447
Segmentation, 849
Segmentation nucleus, 849
Semen, 856
  spermatozoön, 845
Semicircular canals, 754, 768
    Cyon's theory, 769
    Ewald's theory, 768
    reflex center of, 770
Semilunar valves (see heart-valves).
Sensibility, 1
Seminiferous tubules, 845
Sensation of color, 806
Sense spots, 730
Sensory centers, 697
Sensory relay centers, 695
Sensory tract, 658
Serum albumin, 35, 200
    of bacteriolytic cholera, 216
    of blood, 200
    globulin, 35, 200
    normal, 200
Sham feeding, 80
Shock, 208
Side-chain theory, 214
Sighing, 377
Sight, 771
Sigmoid flexure, 94
Sinus of Valsalva, 225
Sixth cranial nerve, 827
Skatol, 130, 453
Skin, 725
  action of liquids on, 732
  action of solids on, 731
  cold spots, 733
  corium, 727
  epidermis, 725
  hot spots, 733
  Krause's end bulbs, 729
  layers of, 726
  radiation and conduction, 524
  reflexes, 678
  rete Malpighii, 727
  stratum corneum, 727
    granulosum, 725
    lucidum, 725
  touch corpuscles of, 728
Sleep, 706
  theories of, 707
Small intestine, 89
    innervation of, 93, 95
Smell, sense of, 742
    anosmia, 747
    center of, 698
    general description of, 743
    hyperosmia, 747
    mechanism of, 746
    nerves of, 744
    olfactory organ, 744
    olfactory sensation, 745
    proper stimulus of, 745
    secondary sensations, 746
    subjective sensations, 746
    uses of, 747
Snoring, 378
Soap, 30

Sobbing, 378
Sodium chloride, 27
    in blood, 198
    in urine, 454
    substitutes for, 27
Solitary glands, 93
Solutions, gram molecule, 142
Somatose, 86
Sound, 569
  height of, 569
  intensity of, 570
  production and modification of, 563
  resonance of, 570
  timbre, 570
Sound-waves, course of, 765
    conduction of, 762
Sounds of heart, 242
    variation in, 245
Special cell-constituents, 7
  sensation, laws of, 725
  senses, 722
Spectra of blood, 194
Spectroscope, 192
Spectroscopic test for blood, 194, 211
Speech, 571
  aphonia, 572
  center of, 573
  defects of, 572
  hoarseness, 572
  stammering, 572
  stuttering, 572
  ventriloquy, 571
Spermatogenic cells, 845
Spermatozoön, 846
  structure of, 846
Sphenopalatine ganglion, 831
Spherical aberration, 794
Sphincter ani, 131
Sphygmogram, 290
Sphymograph, 290
  Dudgeon's, 290
  Marey's, 289
Sphygmometers, 303
  Erlanger's, 304
  Mosso's, 304
  Riva-Rocci's, 303
Sphygmomanometers, 303
Spinal accessory, 839
    distribution, 839
    function, 840
    origin, 839
    pathology, 840
    physiology, 840
Spinal cord, 608
    anterior median groove, 610
    anterior roots, 610, 677
    antero-posterior lateral grooves, 610
    blood-supply, effect of, 674
    centers in, 680
    central canal, 616
    columns of, 617
    conduction of, 675
    commissures of, 622
    coverings of, 609
    degenerations of, 622
    diameter of, 609
    ependyma, 616
    experiments on, 678
    exterior form, 610
    fibers of, 613
    general description of, 610
    gray commissure of, 610
    gray matter of, 611
    internal conformation of, 611
    length of, 609
    minute structure of, 613
    neuroglia, 614
    path of motion in, 677
    path of sensation in, 677
    posterior median fissure, 610
Spinal cord, posterior roots of, 622, 677
    recurrent sensibility of, 676
    reflex action of, 678
      forms of, 673
      laws of, 673
      swiftness of, 673
    skin reflexes in, 678
    suspension of, 610
    systemization of, 616
    tendon reflexes in, 679
    tonus of, 674
    tracts, comma, 621
      of lateral column, 619
      of Lissauer, 621
      of posterior columns, 620
    trophic centers of, 608
    weight of, 610
    white commissure, 610
Spinal ganglion, 676
Spirem, 20
Spirits, 45
Spleen, 410
  effect of injection of dried extract, 411
  function of, 410
  Malpighian corpuscles of, 410
  nervous influences of, 411
  pulp of, 410
  structure of, 410
  trabeculæ, 410
Spongioplasm, 9, 596
Staircase contraction, 273, 549
Stammering, 572
Stannius's experiments, 253
Stapedius, 761
Stapes, 753
Starch, 27
Starling's theory of lymph, 162
Starvation, effects upon proteid, 495
  description, 495
Steapsin, 105
Stearic acid, 30
Stearin, 30
Stercobilin, 131
Stereognosis, 698
Stethograph, 351
Stilling, raphé of, 624
  canal of, 788
Stimulants as accessories, 44
Stimulation fatigue, 549
Stimuli, successive, 552
Stokes-Adams disease, 259
Stomach, 69
  absorption from, 144
  action of agents on, 82
  blood-supply of, 71
  coats of, 69
  glands of, 70
  movements of, 72
  mucous membrane, 70
  nervous control of, 74
  Schuetz's law, 77
  secretion (see gastric juice),75
  secretory nerves of, 81
  structure of, 69
Stomata, free, 154
Strabismus, 810
Stratum complexium, 634
  corneum, 727
  granulosum, 727
  lucidum, 727
  profundum, 634
  zonale, 635
Stromhur, Ludwig's, 313
Struggle for existence, 866
Stuttering, 572
Subarachnoidean space, 609
Subdural space, 609
Sublingual glands, 56
Submaxillary ganglion, 835
Substantia gelatinosa of Rolando, 612

Succi's fast, 497
Succus entericus, 125
    daily secretion, 125
    ferments of, 125, 126
    function of, 125
    specific gravity of, 125
Sugar in urine, 460
    tests for, 461
Sugar (see dextrose).
Sulphur, 455
Sulphuric acid in urine, 455
Superior laryngeal nerve, 369, 568
Superior vermiform process, 685
Superior fovea, 634
Supplemental air, 355
Suprarenal capsules, 412
Sustentacular cells, 845
Survival of the fittest, 866
Swallowing, 58
  of food, 58
  three stages of, 58
  of fluids, 59
  mechanism of, 59
  nervous control of, 60
Sweat (see perspiration), 425
Sweat glands, 425
    experiments on, 425
    nerves of, 426
    number of, 425
    structure of, 425
Sylvian center, 522
Sylvius, fissure of, 643
Sympathetic, the great, 610
    afferent fibers of, 718
    efferent fibers of, 611
    ganglia of, 611
      reflex action of, 621
    general description of, 611
    of abdomen, 719
    of arm, 720
    of head and neck, 719
    of leg, 720
    of pelvis, 719
    of thorax, 719
Synthesis, 469
Syntonin, 35
Syringomyelia, 678
Systemic circulation, 229
Systole of heart, 231
Systolic plateau, 240

TABES dorsalis, 621
Table of oxidation in starvation, 495
Tactile sense, 722
    effect of liquids on, 732
    effects of solids on, 731
    cells, 728
    compound sensations, 732
    illusions, 732
    knowledge gained from, 730
    law of Fechner, 725
    law of sensation, 724
Taste, 737
  center of, 698
  drugs, 740
  effect of drugs on, 740
  general description, 737
  improper stimuli, 739
  intensity of, 739
  nerves of, 738
  organs of, 738
  substances of, 740
  tongue's part in, 737
Taste buds, 739
Taurocholic acid, 114
Tea, 145
Tension, arterial, 296
Teeth, 50
  milk, 50
  number of, 50, 51
Teeth, parts of, 53
  permanent, 51
  structure of, 53, 54
Tegmentum, 638
Teichmann's crystals, 191, 211
Temperature, 509
  at different ages, 511
  cause of variations, 511
  estimation of, 513
  extremes of, 512
  modifying influences, 511
  nerve-centers of, 520
  of animals, 509
    blood, 168, 512
    man, 509
  post mortem, 527
  spots, 733
Tendon reflexes, 679
Tendons in relation to muscle, 536
Tenon's capsule, 789
Tensor tympani muscle, 764
Tetanus of muscle, 554
Tetany, 409
Theory of preformation, 843
Thermal unit, 513
Thermogenic center, 519
Thermoinhibitory center, 521
Thermolysis, 524
Thermolytic center, 22
Thermotaxic center, 519
Thirst, 132
Thoma-Zeiss apparatus, 175
Thoracic duct, 152
Thrombin, 202
Thrombogen, 202
Thrombokinase, 202
Thymus gland, 417
    chemical composition, 417
    extract of, 418
    function of, 418
    results of extirpation of, 418
    structure, 418
Thyro-arytenoideus muscle, 567
Thyroid gland, 400
    function of, 402
    internal secretion of, 406
    lymphatics of, 402
    relation to heart, 407
    results of extirpation of, 404
    structure of, 400
    vessels and nerves of, 401
Tidal air, 355
Timbre of voice, 570
Tissues, 6
  definition of, 6, 17
Tone, 566
Tongue, 48
  in deglutition, 58
  in mastication, 57
  mucous membrane, 50
  nerves of, 50
Tonicity, 555
Touch, 725
Touch center, 702
Touch corpuscles, 728
Toxalbumin, 214
Toxproteins, 214
Toxins, 213
Trachea, 338
Transfusion, 208
Transitional leucocytes, 180
Trapezoid body, 634
Traube-Hering curves, 308
Tricuspid valve, 225
Trifacial, 828
  distribution of, 831
  function of, 831
  irritation of, 833
  motor function of, 833
  origin, 831

Trifacial, pathology of, 833
  physiology of, 831
  reflex actions of, 366, 832
  trophic function of, 833
Trigonum acustici, 628
Trigonum hypoglossi, 628
Trigonum vagi, 628
Trochlear nerve, 825
Trophoblast, 853
Trophic centers, 519
Trypsin, 103, 107
Trypsinogen, 99, 103
Tryptophan, 32
Tube casts, 461
Tuber cinereum, 521
Türck's tract, 617
Tympanum, 751
  mucous membrane of, 751
Tyrotoxicon, 43

UFFELMANN'S test for lactic acid, 87
Uhlenhuth's test for blood, 212, 216
Units of measurement, 513
Urates, 457
Uræmia, 463
Urea, 443, 475
  crystals of, 443
  decomposition of, 443
  excretion of muscular labor, 444
  formation of, 445
  properties of, 443
  quantity of, 444
Ureters, 464
Uric acid, 446, 478
    daily amount of, 448
    formation of, 447
    increased by food, 447
    murexide test for, 449
    quantity of, 448
    sediments, 457
    tests, 449
Urinary apparatus, 463
    bladder, 465
    blood, nerve, lymph supply of, 433
    capacity of, 433
    structure of, 465
    tubules, 437
Urine, 441
  acidity of, 442
    albumin in, 459
    Heller's nitric acid test, 459
  bile pigments of, 452
  coloring matters of, 452
  composition of, 455
  drug pigments of, 454
  fermentation of, 455
  inorganic constituents, 454
  movements of, 464
  nerves, influence of on, 463
  pathological pigments, 453
  quantity of, 441
  reaction of, 441
  secretion of, 462
  sediments of, 458
    oxalic acid, 457
    phosphorus, 458
  specific gravity of, 442
  sugar in, 460
    Fehling's test, 460
    fermentation test for, 461
    phenylhydrazin test for, 461
  temperature of, 441
  theory of secretion of, 461
  tides, 442
  toxicity of, 462
  tube casts, 461
Urobilin, 452
Urochrome, 452
Uroërythrin, 452

Uterus, 861
  secretion, 860
Utricle, 770

VAGINA, 861
Vagus, 261
  accelerator fibers, 268
  depressor fibers, 266
  effect of division of accelerator fibers, 270
  effect of irritation of accelerator fibers, 270
  effect of section of, 261, 368
  effect of sipping upon, 264
  effect of stimulation of, 263
  effect of swallowing liquids upon, 264
  peculiarities of, 263
  pneumonia, 368
  relation to blood-pressure, 297, 308
Valves of heart, 225
Valvulæ connivents, 90
Variation, 866
Vasa vasorum, 279
Vasoconstrictors, 321
    effect of irritation of, 321
    effect of section of, 321
  differences from vasodilators, 326
  of abdominal viscera, 324
  of extremities, 324
  of head, 323
  of lungs, 325
Vasodilators, 325
  path of, 325
  recognition of, 326
  theory of action of, 327
Vasomotor nerves, 321
    effect of section of, 321
    effect of stimulation of, 321
    pathologic conditions of, 327
Vasomotor system, 320
    centers of, 327
    function of, 321
    nerves of, 321
    reflexes of, 329
Vegetable cell, 6
Vegetable foods, 43
Veins, 279
  blood-pressure in, 309
  coats of, 279
  lymph and nerve supply, 279
  portal vein, 110
  rate of blood in, 314
  tension in, 309
  valves of, 279
  vasa vasorum of, 280
Venom, 218
Venous blood, 170
Venous circulation, 318
Venous pulse, 238, 258, 310
Ventilation, 396
Ventricles of heart, 229
Ventricles of larynx, 565
Ventriloquy, 571
Vermis, 692
Vesicospinal centers, 466
Vessel innervation, advantages of, 329
Vestibular nerve, 759
Vestibular nucleus, 759
Vestibule, 755
Vestibulo-spinal tract, 620
Vibrations in ear, 766
Villi, 90, 155
  epithelial cells of, 91
  goblet cells of, 91
  of intestines, 90
  structure of, 91, 92
Vision, accommodation, 794
  acuteness of, 800
  after-images, 810
  aqueous humor, 788

Vision, astigmatism, 798
  binocular vision, 811
  center of, 799
  chromatic aberration, 794
  color vision, 807
  complementary colors, 807
  crystalline lens, 781
  Daltonism, 807
  dioptrics, 793
  hypermetropia, 796
  irradiation, 808
  lacrymal secretion, 814
  lenses, 798
  lymphatics, 799
  movements of eyes, 812
  myopia, 800
  ophthalmoscope, 814
  optic nerve, 785
  perception of light, 792
  perimeter, 815
  phosphenes, 809
  presbyopia, 796
  retina, 782
  retinal epithelium, 785
  rhodopsin, 785, 804
  sensation of color, 806
  Snellen's test-types, 803
  spherical aberration, 794
  transmission of light, 771
  visual angle, 802
    apparatus (see eye).
      structure of, 772
    purple, 785
    area, 815
    field, 818
    line, 802
Vital capacity, 355
Vitellin, 40
Vitreous humor, 788
Vocal cords, 565, 568
    conditions of, 568
    false, 565
    true, 565
Voice and speech, 569
    height of, 569
    organ of, 568
    range of, 570
Vomiting, 87
  causes, 88, 571
  mechanism of, 87, 88
  nerve center, 88
Von Bezold's ganglion, 251
Vowels and consonants, 571

WALLERIAN degeneration, 676
Warm-blooded animals, 509
Water, 26
  daily amount, 26
  drinking, 26
  in fæces, 130
  in metabolism, 484
Weber's schema of circulation, 283
Wheat, 44
Whey, 42
Widal reaction, 215
White columns, 617
White corpuscles (see blood-corpuscles), 179
Wine, 42
Wing muscles of insect, 533
Wirsung's duct, 98
Word-centers, 573, 699
    auditory, 573, 698
    visual, 572, 698
Work, effect upon destruction of proteid, 546
Wrisberg's cartilages, 565

XANTHIN in urine, 450
Xanthoproteic test for proteids, 36

YAWN, 377

ZONULE of Zinn, 795
Zymogen, 99
Zymoids, 213

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